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National Proceedings: Forest and Conservation Nursery Associations 1999, 2000, and 2001



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Abstract

The National Proceedings contains articles presented at regional meetings during 1999, 2000, and 2001. **1999:** The joint meeting of the **Northeastern and Western Forest and Conservation Nursery Associations** was held at the Gateway Conference Center in Ames, Iowa, on July 12–15. Hosts were the Iowa Department of Natural Resources, Cascade Forestry Nursery, and the USDA Forest Service. The meeting theme was *Nursery Challenges for the New Millennium.* Morning technical sessions were followed by afternoon tours of the Pioneer Seed Biotechnology Labs, the Bear Creek Riparian Buffer Project area, and the Iowa Department of Natural Resources nursery. **2000:** The **Southern Forest Nursery Association** conference, *Growing Green in the New Millenium*, was held June 26–29 at the Adam's Mark Hotel in the historic district of Mobile, Alabama. The meeting, *Growing Green in the New Millennium*, was hosted by the Alabama Forestry Commission. Technical sessions were followed by tours of the E.A. Hauss Nursery in Atmore and the Knud Nielson Company in Evergreen. The **Northeastern Nursery Conference** was held at the House on the Rock Resort in Spring Green, Wisconsin, on July 5–8. The meeting, *Nurseries for the Future*, was hosted by the Wisconsin Department of Natural Resources and the Wisconsin Nursery Association. In addition to the technical sessions, participants toured the Wilson State Nursery. Members of the **Western Forest and Conservation Nursery Association** conducted their meeting August 22–25 at the King Kamehameha Kona Beach Hotel in Kailua-Kona, Hawaii. The meeting was hosted by the Hawaii Department of Forestry and Wildlife. Technical presentations covered operational nursery practices from around the world. Tours included the native plant nursery at Volcanoes National Park and the Kamuela State Forest Nursery. **2001:** Toftrees Conference Center in State College, Pennsylvania, was the site for the **Northeastern Nursery Conference** held July 23–26. The meeting, *Sustainable Nurseries–Sustainable Forests*, was hosted by Penn Nursery. The **Western Forest and Conservation Nursery Association** conducted their meeting July 30–August 3 at Fort Lewis College in Durango, Colorado. The meeting was hosted by the Colorado State Forest Service and tours included the BIA Southern Ute Forest Nursery and Mesa Verde National Park.

Key Words

bareroot nursery, container nursery, nursery practices, fertilization, pesticides, seeds, reforestation, plant propagation, native plants, tree physiology

Papers were edited to a uniform style; however, authors are responsible for the content and accuracy of their papers.

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NATIONAL PROCEEDINGS:
FOREST AND CONSERVATION NURSERY ASSOCIATIONS
1999, 2000, AND 2001

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Searchable Internet Database—www.fcnanet.org

Papers published in the National Proceedings (1994 to present) are available in portable document format (PDF) on the Forest and Conservation Nursery Association Internet site: http://www.fcnanet.org. This database can be searched by author and keyword and includes papers published in the regional nursery proceedings (Western, Intermountain, Northeastern, and Southern) prior to 1994.

On-line Nursery Information

Visit the Reforestation, Nurseries, and Genetics Resources Internet site: http://rngr.fs.fed.us

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NORTHEASTERN AND WESTERN FOREST AND CONSERVATION NURSERY ASSOCIATIONS CONFERENCE

AMES, IA

JULY 12—15, 1999

THE CASCADE FORESTRY SERVICE NURSERY

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Key Words

Bareroot nursery, forest nursery, native plants, hardwood, conifer

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Cascade Forestry Service, Inc., is a private reforestation nursery and service company that has grown from a shoestring operation into an employee-owned company that both produces reforestation trees and assists landowners with forestry development and management.

The Northeastern Forest and Conservation Nursery Association has proven instrumental in Cascade Forestry's growth and development, particularly through allowing us to participate in their annual meetings. We thank the Iowa Department of Natural Resources for inviting us to cohost this year's meeting. After all, as members of the association, we share a common goal—to provide the public with quality seedlings for restocking existing forests and establishing new ones. It is this opportunity to share ideas and learn new and better ways to deal with forest nursery challenges that is the very basis for the association.

Cascade Forestry Service was founded in 1975 by Leo Frueh, 1 of 9 children who grew up on a small farm near Melcher, Iowa. After graduating from Iowa State University in 1963, Leo served as a Peace Corps forester for 2 years in Nepal. Upon returning to this country, he worked for the USDA Forest Service in West Virginia, where he met his wife, Mary, who was working as a Vista volunteer.

In 1967, Leo and Mary returned to Iowa where Leo began work as a log buyer for Bacon Veneer, a long-established veneer company in Dubuque. He later worked as a log buyer for a private logger before starting Cascade Forestry Service. Leo and a partner managed to secure a $20,000 loan to develop a nursery on a 13-acre piece of land, buy equipment for tree planting and timber stand improvement, and provide cash flow for the 2 partners and a part-time secretary.

Today, Cascade Forestry Service produces more than 1.5 million hardwood seedlings and conifer transplants annually, plants 1,500 acres of trees per year, and does timber stand improvement and forestry consulting in Iowa, Illinois, Minnesota, Missouri, Nebraska, and Wisconsin. Current staffing includes 10 full-time employees with a peak seasonal employment of almost 80 people during the busy spring season.

Cascade Forestry's growing fields started with a 13-acre creek bottom that we still use. We have since piecemealed together an additional 57 acres of production area in 6 adjacent fields. To irrigate this expanded area we now have 3 new portable pump units capable of much greater pumping capacities in addition to a 190-foot well. The pump units were desperately needed the past 2 years to accommodate an increase in our production area.

The original combined cooler and administration building was our only building until 1991 when we expanded to a location 5 miles away beside a highway. A more strategic location, this facility provided much greater cold storage and shipping capacity, as well as an enlarged office complex. However, we have outgrown this building during the past 3 years, as witnessed by the fact that last year we rented 13 refrigerated trailers for additional cooler storage space. Similarly, for the past 4 years, we have rented space in a neighbor's cattle shed for grading operations. We are currently in the process of planning for a major

new building to accommodate future processing and cold storage needs.

We are also in search of more and better land. We recently rented an additional 10 acres, and are looking for more. Our soil types vary considerably, and we'd like our ground to be more uniform, of higher organic content, and better suited for nursery production than some of our existing areas.

Like most nurseries, we have a long list of equipment needs. Some of our recent acquisitions include a bedformer, 2 trucks, 2 irrigation pumps and pipe, a tractor, and 2 seeders. But the list of needs continues, despite measurable gains this past year.

Seed collection becomes more challenging each year as the demand for seed has escalated. We collect a limited amount ourselves, but rely mainly on seed collectors within a several hundred-mile radius to supply the majority of our seeds.

Cascade Forestry also concentrates on native species within the area—zones 4 and 5. While oaks, walnut, and ash have traditionally been the mainstay of our production, we find increasing interest in species diversity. Consequently, we are growing an increasing number of hickories, Kentucky coffee tree, cherry, and endangered species like butternut and American chestnut. The Conservation Reserve Program (CRP) has produced a heavy demand for native shrubs, and we are also trying to fill some of this demand.

In addition to growing hardwoods, we currently buy 2-year-old conifer seedlings and raise them 2 additional years at lower bed densities for resale as larger transplant stock. We now grow approximately 50 species of trees and shrubs. We also sell potted conifers for windbreaks.

Besides increasing the number of species grown, we have also increased overall production numbers from about 750,000 plants 2 years ago to almost 1.5 million this year. Within 2 additional years, we expect that target to reach or exceed 2.5 million trees. Our goal is to produce the majority of seedlings we sell. Currently we augment our shortfalls in production with purchased stock from other nurseries.

Cascade Forestry also strives to produce heavy-rooted seedlings. To accomplish this, we undercut many of the hardwood species and work to keep bed densities low. We use a Silver Mountain undercutter, which allows us the flexibility to undercut select species (for example, oaks) during the first growing season.

Our service crews planted 1,338 acres of land for 101 landowners this past spring. Jobs ranged in size from 1 acre to 200 acres and stretched from Winona, Minnesota to central Missouri, and from the Nebraska border to the suburbs of Chicago. To accomplish this task, we had 4 machine-planting crews and 1 hand-planting crew.

Projects included: farmstead windbreaks; CRP plantings; riparian plantings; a direct seeding project; a pipeline project that included 30 individual planting sites stretching from Tama, Iowa, to Joliet, Illinois; a planting for the Illinois Department of Transportation; and the establishment of a bur oak savanna for the Wisconsin Department of Natural Resources.

Two years ago, we instituted a survival guarantee for plantings we do using our stock. This guarantee has become a standard practice for us. Because of it, many foresters now allow us to plant later than the established deadlines, and this has, in effect, increased the length of our planting season. This year, for example, we had 3 machine-planting crews active through the third week of June.

With the increased demand for tree plantings, Cascade Forestry Service has been doing more fall planting; we believe this is a viable option on certain sites with certain species. We also anticipate increased interest in direct seeding and have tried some innovative approaches to this practice.

As we gaze into our crystal ball, we realize the increasing importance of sharing information—whether about herbicides, genetics, bed density, species hardiness, the use of global positioning systems, or the opportunities presented by genetic alteration. We look forward to actively participating in the association in the future, and we invite all members to give us a call or to stop by our nursery at any time for a tour.

INSTALLING A PRACTICAL RESEARCH PROJECT AND INTERPRETING RESEARCH RESULTS

R. KASTEN DUMROESE AND DAVID L. WENNY

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Abstract

We review the basic concepts of science and research and the scientific process. Using an example from a bareroot nursery, we show how a practical research project can be done at any type of nursery, meshing sound statistical principles with limitations of busy nursery managers.

Key Words

Experimental design, research, bareroot nursery, container nursery, statistics

Most growers already do nursery research, whether they realized it or not. Have you ever done the following: 1) contemplate a problem at the nursery; 2) after reading an article or discussion with a colleague, had an idea how that problem might be corrected; 3) put in trials to test your guess; 4) decide if your idea solved the problem? If so, you have done scientific research following the research process. Depending on how well the research is done, the research process can provide accurate and useful information, or it can be a waste of time yielding papers and conclusions that mean nothing. Our objective is to help growers design projects that yield meaningful results. The bonus is that if you can design a good experiment, you can also tell if published research results were generated through a good experiment and worthy of consideration.

WHAT IS RESEARCH?

Science is the possession of knowledge attained through study or practice. Research is the systematic search for new knowledge. Scientific research, simply stated, is the testing (systematic, controlled, empirical, and critical investigation) of ideas (hypothetical propositions about presumed relations among natural phenomena) generated by intuition (Stock 1985). Scientific research is carried out using the scientific method, which has distinct steps (Table 1).

Table 1. Steps in the scientific method.

Steps	Example
Natural phenomena are observed	Ships sailing from port gradually disappear from sight, the tops of the masts being the last part seen.
The problem is defined	If the world is flat, why do ships gradually disappear from bottom to top?
A hypothesis (a guess) is made	The world is not flat, but round.
Test	Sail west from port and see if you return to where you started without falling off the end.
Theory	The world is round.

Theories are general explanations for natural events, useful to understand, predict, and control natural phenomena. For installing practical research projects at our nurseries, we're probably less concerned with developing broad, sweeping theories of the universe, but rather, for example, whether or not it's cost effective, in terms of improved growth, to double the amount of magnesium (Mg) we apply to 1+0 black cherry. The research process we generally follow looks like this: 1) *Observation:* practical experience, literature review, conversations with other nursery managers; 2) *Problem definition:* specific question(s) asked; 3) *Hypothesis generated:* objectives defined and methods selected for testing the hypothesis; 4) *Testing:* data collected, analyzed, and interpreted; 5) *Hypothesis accepted, rejected, or modified* (Stock 1985).

Although this process seems straightforward, and when reading published research it sounds as if the researchers followed these steps systematically, the research process is dynamic and subject to change as more information is discovered.

Following The Process—an Example

It really doesn't matter whether you grow bareroot or container seedlings—experiments are designed in the same manner. To see how an experiment might be designed, let's follow an example of doubling the rate of magnesium (Mg) to improve growth of 1+0 black cherry.

Observation

When a usually competent technician accidentally applied 2X the normal amount of Mg to a bareroot bed of 1+0 black cherry, those seedlings appeared taller than an adjacent bed. After measuring 100 random seedlings from each bed we noted that those receiving 2X Mg were 12 in (30 cm) taller. What can we conclude from this? Not much. This is an observational study—there was no control over which seedlings were in each treatment (1X or 2X Mg). Were growth differences due to 2X Mg? Maybe, but growth might have been effected by seed source, soil conditions, or because weeders didn't get to the 1X bed for an extra 3 weeks because of wet weather. Seed source, soil conditions, and weeds have **confounded** the issue of whether or not it was solely the Mg fertilizer. We can't tell treatment effects for sure, all we can say is that 2X Mg was associated with increased growth. However, in talking with other nursery managers, they also report intriguing observations that extra Mg increases growth. After checking issues of Forest Nursery Notes, we find some papers dealing with Mg nutrition. Based on our personal observations, discussion with colleagues, and reading papers (see sidebar), we think seedling growth will benefit from increasing the Mg fertilization rate.

Problem Definition

With what we've seen and heard, our problem statement is: Our 1+0 black cherry seedlings don't get enough Mg fertilizer.

Hypothesis

From this problem definition, we could state the following hypothesis: *Doubling Mg fertilizer increases growth of 1+0 black cherry.* How would we test this hypothesis? As broad as this statement is, we would have to test all 1+0 black cherry seedlings, in all nurseries, on all possible nursery soil types, and all possible seed sources. Oh yeah, and we'd have to do it over a couple of different growing seasons to make sure weather didn't affect our results too. Often the hardest part of the research process is defining a concise, achievable objective. Perhaps this hypothesis more succinctly states our best guess:

Doubling the amount of Mg applied to 1+0 black cherry grown in fields 6 and 14 at the Iowa DNR State Forest Nursery in Ames increases seedling height.

Being good statisticians, we then formulate (why we do this will become apparent later) a *null hypothesis* for testing: *Seedling heights of 1+0 black cherry grown in fields 6 and 14 at the Iowa DNR State Forest Nursery in Ames fertilized with 1X and 2X rates of Mg* **are the same**.

Testing

Now we are ready to design our experiment. Randomly assigning seedlings to treatments is the most important part of the design. Randomization ensures that other than the treatment, systematic differences between or among groups of seedlings are lacking, allowing us to conclude the treatment (2X Mg) is causing the observed result (changes in seedling height) in the experiment (see Ganio 1997).

Reading Scientific Papers

Armson (1993) points out several things to consider when reading scientific papers: 1) just because a paper appears in a journal that requires peer review, don't assume the information is correct; 2) don't assume that authors citing previous research did so correctly; 3) don't jump to conclusions—if you only read the abstract or conclusions with the purpose of deciding whether or not the authors agree with your point of view, bias may enter the decision. Papers must be read thoroughly, critically, and with an open mind. Check the references section for titles of similar work and read them too.

From our hypothesis, we want to test if 2X Mg increases seedling height over that of our usual practice (1X Mg). Therefore, we have 2 treatments (1X and 2X Mg). Our 1X treatment serves as our "control" because this is the usual fertilization rate. Without a control to compare we can't be sure our treatment has an effect. **One of the most common mistakes in installing a practical research study is failure to have an adequate control.** Our hypothesis is rather broad in that we think this will work for 1+0 black cherry—implying all possible seed sources of black cherry we might ever grow at the nursery. It's not realistic to try to include every possible seed source, but at least 3 should be included in the test. If only 1 seed source is used, and it happens to have a genetic trait that yields a growth response to Mg, we might conclude that 2X Mg is beneficial to all seed sources of black cherry when in fact it only favors that particular seed source. In our hypothesis, we also want to check the effects of Mg in the 2 fields we grow black cherry (6 and 14). Let's assume that the soil in field 6 is fairly uniform and the soil in field 14 is also fairly uniform, although they are not necessarily uniform with each other.

In order to determine that it's the Mg level that is affecting growth, we must design our experiment so that factor (Mg level) is represented and not confounded. We need a location where the entire test plot has similar conditions so the only outside variable is in the treatment (Columbo 1999). Okay, how about we put 1X Mg on all the black cherry in field 6 and 2X Mg on seedlings in field 14? Bad idea. Differences in soil conditions between the 2 fields would confound with the Mg level. We won't be able to tell if growth differences are due to Mg level or inherent differences in soil conditions. And, if Illinois seed sources were grown in field 6 while field 14 had Iowa seed sources, we wouldn't be able to tell if any growth affects were due to Mg levels or the inherent genetic differences between black cherry from Illinois and Iowa. Again, the experiment would be confounded.

To avoid confounding, researchers generally design experiments into blocks. In our test, we could call each seed source a block. Each block would receive both treatments (levels of Mg). We could also call our fields blocks, and each field block would receive each seed source which we just decided would receive both levels of Mg. Each field (2) – seed source (3) – Mg level (2) combination (there are 12; 2 x 3 x 2 = 12) is a plot. Plots require replication so we can conclude with certainty whether the treatments are actually different. Growth differences between the 1X and 2X Mg rates should be larger than the growth differences between replicates of the experimental units in order for the Mg rates to be considered different. A minimum of 3 replicates of each plot is encouraged—4 to 6 is better.

Okay, we have 12 plots replicated 4 times—48 distinct experimental units. Our next step is lining them out in the fields. Think in terms of dividing the field into a grid with an equal number of plants in each grid (Columbo 1999). In a perfect world with the perfect study, seed sources and Mg levels would be randomly assigned across each field (throughout the grid; Figure 1). Portions of several beds would have multiple seed sources and Mg levels, allowing us to compare seedling growth among seed sources and magnesium levels with the same precision. In real life, this would make lifting and maintaining lot integrity difficult, and cause employees to grumble. We assumed earlier that soil conditions within each field are similar, and because we are less interested in comparing growth among the seed sources and wish to focus mainly on magnesium levels, we can manipulate the design. Let's assume we plan to plant 100 bed ft (30.5 m) of 3 sources of black cherry. Although not statistically perfect, we can lay our 8 experimental units (2 levels of Mg, 4 replicates) in each seed source (Figure 2). If we divide 100 by 8, each unit could be 12.5 ft (3.8 m) long. However,

Rep 1	Rep 2	Rep 3	Rep 4
1X-A	1X-C	2X-A	2X-B
2X-B	2X-A	1X-C	2X-C
2X-A	1X-B	1X-A	2X-A
1X-C	1X-A	2X-C	1X-B
1X-B	2X-C	2X-B	1X-A
2X-C	2X-B	1X-B	1X-C

Figure 1. A completely randomized layout of plots. The 6 combinations of magnesium levels (1X, 2X) and seed source (A, B, C) are randomly assigned within each bed (column).

A	B	C	
2X	1X	1X	Rep 1
1X	2X	2X	
1X	2X	2X	Rep 2
2X	1X	1X	
1X	2X	2X	Rep 3
2X	1X	1X	
2X	2X	1X	Rep 4
1X	1X	2X	

Figure 2. In this layout, magnesium levels (1X, 2X) are randomly replicated 4 times within a bed of each seed source (A, B, C).

we want to avoid using the first and last 6 ft (1.8 m) of the bed because of the variability in seedbed density caused by starting and stopping the seed drill. That leaves us 88 ft (26.8 m). We should also have a buffer (3 ft [0.9 m]) between treatments to adjust the fertilizer rate of our equipment. That leaves us 67 ft (20.4 m), or about 8 ft (2.4 m) per experimental unit.

After drilling the black cherry, measure the bed as shown in Figure 3. The first 6 ft (1.8 m) is avoided, then an 8-ft-long plot, a 3-ft-long buffer, an 8-ft-long plot (2.4 m, 0.9 m, 2.4 m) and so on. Our Mg levels are then randomly assigned to each plot (Figure 3). We repeat the process for each of the remaining 2 seed sources in field 6. Moving our equipment over to field 14, we repeat the process with the same 3 seed sources, 2 Mg levels, and 4 replicates. **Make a detailed map and store it in a safe place.**

When the Mg is applied, appropriate plots are fertilized with 1X and 2X rates. Buffer strips between plots serve as the transition zone between fertilizer levels. It's often best to use a code to identify plots, hiding the treatment identity helps reduce any bias that might occur during data collection and evaluation (Columbo 1999). **Add the codes to your map and store them in a safe place.**

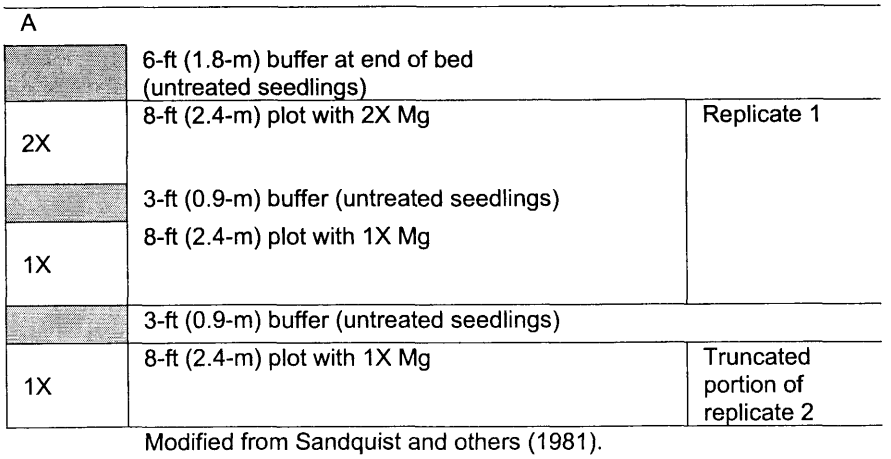


Figure 3. Spacing and location of the first 3 plots for Seed Source A shown in Figure 2.

From the time of drilling until the end of the growing season, implement cultural treatments to the experiment concurrently. That is, if you top dress with ammonium sulfate, top dress all of the plots with the same fertilizer rate. Root prune or apply pesticides to all plots on the same day. The more uniform cultural practices are applied to test plots, the more likely we'll be able to measure treatment effects—what we really want to know.

Measuring Seedlings

We hypothesized that 2X Mg would increase height growth. At the end of the growing season we'll need to measure seedlings to see if indeed this is true. In a perfect world, the number of seedlings to measure is determined by statistical methods. Often, the perfect statistical answer must be tempered by real-world considerations of time and money. Assuming seeds were drilled to achieve 5 seedlings per square foot (55/m^2), each plot has about 160 trees. We want to avoid measuring seedlings around the outer edges because of "the edge effect" where seedling growth can be influenced by lower density, higher soil compaction in the wheel ruts, more light, and so on. So if we planted on 6 in (15 cm) rows in a 4-ft-wide (1.2-m-wide) bed we have 7 rows. We should avoid measuring seedlings in the 2 outside rows and for at least 1 ft (30 cm) on each end of the plot (Figure 4). That leaves about 70 seedlings in the center of each plot for measurement. If we measure every seedling in every plot in both fields, we'll have to measure 3360 seedlings (2 Mg levels x 3 seed sources x 4 replicates x 2 fields x 70 seedlings = 3360). That's a lot of seedlings. We could sub-sample each plot by systematically measuring every fifth seedling we come to in each row (5 per row, 3 interior rows; 15 seedlings per plot). We would then measure a more realistic 720 seedlings. Have the same person collect data from each treatment at the same time to reduce adding unwanted variability (Columbo 1999).

Accepting, Rejecting, or Modifying the Hypothesis

Statistics—Striking Fear Into The Hearts of Many

For many of us, statistics seems like a foreign language. Looking at a statistics textbook becomes a substitute for insomnia drugs. However, remember we use statistics to do 2 things: 1) estimate population parameters; and 2) test hypotheses about those parameters. In other words and for our example, we use statistics to estimate the heights of our seedling populations that received 1X or 2X Mg, and then use those estimates to see if our null hypothesis is correct (all seedlings had the same height regardless of Mg rate).

Remember that statistics don't prove anything—statistics only deal with probabilities, not immutable absolutes (Freese 1980). In other words, statistics only compute the probability of something happening and leave it to the researcher to draw conclusions from that probability. Usually in designing an experiment, a researcher will select a probability to use for testing the null hypothesis (for example, 0.05 or 0.01). Often researchers use the 0.05 level of probability. If statistics show that the probability of the null hypothesis occurring is < 0.05, we infer that differences seen between treatments have a less than one-in-twenty chance of occurring by chance. In other words, 19 out of 20 times the difference is due to the treatment. In our experiment, if we ran statistics and found that the probability of the null hypothesis being true (seedlings have the same height in 1X and 2X Mg treatments) was < 0.05, we could infer this is not true (reject the hypothesis; seedlings in 1X are not the same height as seedlings in 2X) because the heights are different 19 out of 20 times (the probability of the heights being the same is less than one-in-twenty).

Okay, that's nice, but how would most nursery managers that don't have access to powerful statistical analysis software like Systat or SAS analyze data? Both an analysis of variance or t-test can be done by hand, and hand calculations are explained well in Freese (1980). Some spreadsheet programs like Excel have built-in statistical packages, but if you don't understand the process by which the computer is generating the results, how will you know if the answer is correct?

This hypothetical design allows us to partition variation to different sources (fields, seed sources, Mg fertilizer levels). It is a powerful tool for evaluating treatment effects. If complete data analysis cannot be done by hand or computer program, and if a good statistician isn't available to

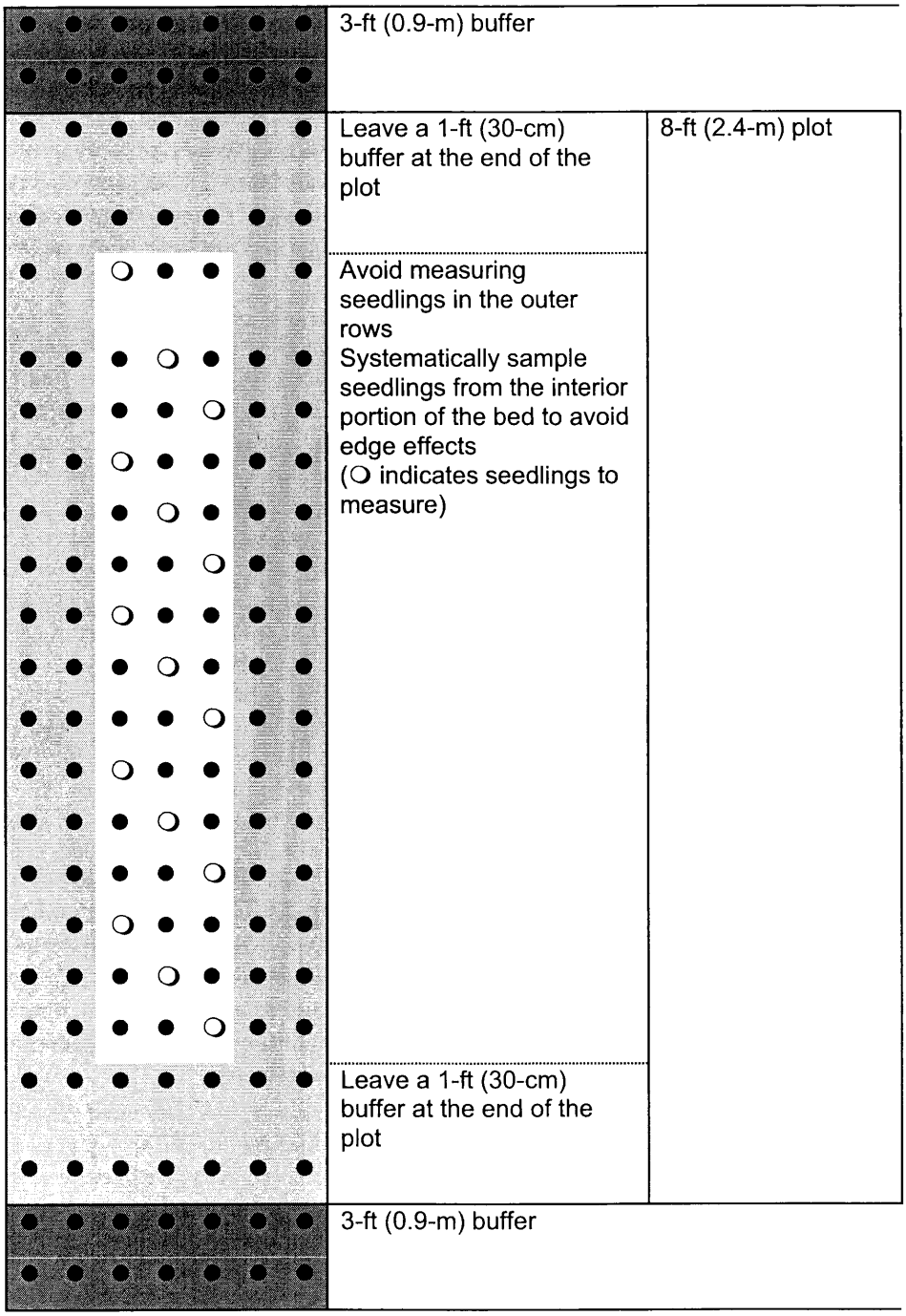


Figure 4. To reduce the variability of measured seedlings, avoid measuring seedlings on the edges of the treatment plot. Depending on the number of remaining seedlings in the plot, a systematic sampling of seedlings might be most efficient in terms of labor.

help with complete analysis, some basic comparisons can still be made.

Means—a Basic Comparison

An easy way to compare treatments is to compare arithmetic means. Means are the average value of all the measured values in our experimental unit, or plot. Spreadsheets and calculators can give us the mean, along with a standard deviation and confidence intervals.

Standard deviation characterizes the dispersion of individuals around the mean. It provides some idea whether most of the individuals in a population are close to the mean or spread out. If the means are normally distributed, 67% of all individuals will be within 1 standard deviation of the mean, and 95% will be within 2 standard deviations, and 99% within 2.6 standard deviations.

Confidence intervals (CI) provide a range of values inside which the true mean of the population resides. CI provide an indication of the reliability of the mean. Usually the limits are set at a 95% or 99% level. If you choose a 95% CI (0.05 level of probability), the result the spreadsheet gives you tells you that unless a one-in-twenty chance has occurred in sampling, the population mean is somewhere within the CI (Freese 1980). Very wide CI indicate a lot of variability. Collecting more samples from the treatment plots may, or may not, yield a better estimate of the mean (narrower CI).

Is It Significant?

For most growers, the whole idea of statistical significance and comparing means boils down to 1 simple question: *What's important to me, the grower?* Sometimes treatments can be significantly different, but not biologically or economically significant. If 2X-treated black cherry were 2 in (5 cm) taller than the 1X, and that was statistically different, would it be important to you as a grower? What if they were 6 in (15 cm) taller? Or 12 in (30 cm) taller? What if the treatment indeed made them taller, but less sturdy? Or increased height but made them more susceptible to insects? As growers we might be interested in both the qualitative and quantitative aspects of our results.

Summary

Define your problem, and subsequent hypothesis, concisely—have very specific objectives of what you want to evaluate. Use blocking to eliminate confounding. Randomly assign seedlings to treatments. Include a control treatment. Treat all seedlings the same, except for the treatment itself, to reduce the chance of confounding. Although powerful statistical packages can be useful, for most growers, a comparison of means between or among treatment populations is probably sufficient enough to determine whether or not the treatment is biologically and economically significant and should become the new nursery standard. Growers should share their results by publishing.

Acknowledgments

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Using Electrolyte Leakage Tests to Determine Lifting Windows and Detect Tissue Damage

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Key Words

Seedling quality, conductivity, FIEL

Physiological testing is rapidly coming into use as a means to determine the condition of nursery stock and predict how it will respond to treatment or use. One such test, the electrolyte leakage test, can be used to measure cold hardiness and detect tissue damage. The principle of this test is that when cell membranes are damaged, electrolytes leak out into the water in which the tissue is immersed and can be measured by the conductivity of the solution. The test for damage is nonspecific in that anything that damages the membranes, such as cold, heat, disease, or mechanical injury, will cause electrolyte leakage. In the case of cold hardiness measurement, we know the damaging agent because we freeze the tissue.

Why measure cold hardiness? This is an important attribute in its own right, but it is also well correlated with a number of other important attributes such as bud dormancy, root growth potential, and ability to be lifted and successfully stored overwinter.

We have used the measurement of cold hardiness to determine when conifer seedlings are ready to be fall lifted, so that they will store well overwinter and survive well when outplanted; these results have been reported at previous nursery meetings. Now, starting with 2 species of juniper, we have created a computer program in which you enter the current date, results of a cold hardiness measurement made in the early fall, and the threshold of cold hardiness needed for high outplanting survival. The program will compute the number of days before you can begin lifting.

Running the Test

Sample preparation

The sample can be any tissue. In measuring cold hardiness to determine the lifting windows of conifers we use foliage because it is available year-round, and it is nondestructive of the trees. However, stems or roots can also be used, if either is the critical tissue.

Day 1: Cut the sample into 1-cm segments and place 10 of the segments, cut at both ends, into each of 28 12- by 100-mm culture tubes. Add 0.5 ml distilled water and a few grains of washed quartz sand. Place 4 of the tubes in a refrigerator at about 2 °C. These are the control samples that measure the amount of electrolytes that leak out when there is no damage except for the cut ends. The rest of the samples are arranged in 6 groups of 4, and at least one tube in each group is fitted with a thermocouple immersed in the liquid and connected to a readout device. Cap each tube with a vented cap. Place the rack of tubes in a styrofoam box, and set it inside a chest freezer.

Monitor the decrease in temperature, and when the liquid reaches -2 to -3 °C, shake the tubes. This will cause the sand to nucleate the water and freeze it. You will know this has happened because the temperature of the liquid plus ice will rise to 0 °C. It is important that ice be in contact with the tissue and that it is frozen at as warm a temperature as possible to avoid artifacts. Thereafter, adjust the lid of the box and/or temperature of the freezer so that the decrease in temperature is no more than 5 °C per hour.

In order to get a precise measurement you need to have some idea of how cold hardy the tissue is. Select 6 target temperatures that you expect will span the range from no damage to a complete kill. As a group of tubes reaches each of the successively lower temperatures, remove them and place them in a refrigerator to thaw.

After all of the tubes have been frozen to their target temperatures and thawed, add 5.5 ml distilled water and put them on an orbital shaker at about 120 rpm. The surface of the water should be rotating and agitating the foliage, but there should be no danger that the tubes would spill or be thrown off the shaker.

Day 2: Leave the tubes on the shaker for about 20 hours. Measure the conductivity, being careful not lose any foliage or transfer it from one tube to the next. Start with the controls and proceed to groups frozen to successively lower temperatures. This way you can measure one tube after another without having to clean the probe between tubes. The readings can be recorded on a form or entered directly into a computer spreadsheet. If you have selected the target temperatures correctly, you will notice that the conductivity rises with lower freezing temperature.

Next, recap the tubes, place them in beakers of water, and boil for 20 minutes. This is to kill the tissue completely and release all of the electrolytes that can leak out. Put the tubes back on the shaker overnight for about 20 hours.

Day 3: Measure the conductivity again. This time the conductivity will be high in all of the tubes. Next, package the data in an ASCII file named FIELCOND.DAT and run FIEL.EXE (Appendix 1). The program subtracts the conductivity of the unfrozen controls from that of the frozen samples and then calculates an index of injury for each frozen sample. This represents the proportion of the total electrolytes that leaked out in response to the freezing.

Sometimes the results are obvious by inspection, but it is better if you have a graphics program that will accept a data set and plot index of injury (Y axis) against freezing temperature (X axis) (Figure 1). We use the 50% index of injury as the benchmark for cold hardiness because it is usually near the midpoint on the curve and has the smallest confidence interval.

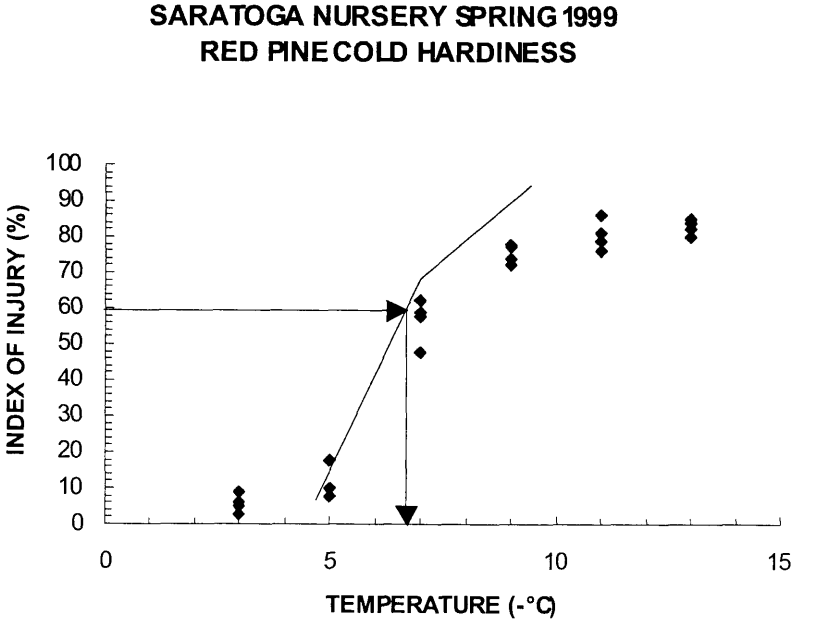


Figure 1. To determine the temperature of the 50% index of injury graphically, plot the points as shown. Draw lines that best fit the data through the part of the curve that includes the 50% index of injury. Where the drawn line crosses the 50% level, project down to the horizontal axis and read the temperature.

Detection of damage: Another use of the electrolyte leakage test is to determine whether trees have been damaged. In this case the tissue selected should be the one on which the damage is suspected. For instance, if container stock has recently been moved out of the greenhouse and is subjected to an unexpectedly cold freeze, the partially lignified new shoot tips would be the most vulnerable.

Take samples of the tissue that may be damaged. For the control, take samples of comparable tissue that you are sure is not damaged. Ten is a good number of replications for each. Place the samples in culture tubes in sufficient distilled water to cover them (the same volume in each), and place them on the shaker for 20 hours. From here on, the procedure is the same as for the measurement of cold hardiness. To run FIEL.EXE code the control temperature as +1 and the test samples as -1.

Our experience has been that if the index of injury is 10% or less, the trees will recover. At a 30% index of injury, the trees are badly damaged and not shippable. At 50%, they are mostly dead.

APPENDIX ONE

Program File

Calculation of Index of Injury for grouped data based on:

1) averaged control data within the group, or

2) control datum for each individual within the group

User is interactively prompted to specify calculation method

Program input is from file FIELCOND.DAT

1) Data for each group should reside in contiguous records

2) Control data should be identified with TEMPERATURE=1

3) For individual calculation approach, control data must be grouped preceding treatment data, and be in the same order

Format of data input is:

Col		
Group ID	1-7	up to 7 numbers and/or characters
Temperature	8-12	1=CONTROL, otherwise negative
Replicate No.	13-14	up to 2-digit number
CONBB	15-19	conductivity before boiling
CONAB	20-24	conductivity after boiling

Program output is to file INJURY.DAT

Format of data output is:

Col	
Group ID	1-7
Temperature	9-13
Rep ID	15-16
Relative Conductivity (percent)	18-22
Index of Injury (percent)	24-28

THE SCIENCE AND APPLICATION OF FOREST CARBON PROJECTS

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Key Words

Global warming, carbon sequestration, tree planting

This year—1999, now in its 7th month—is well on its way to becoming the hottest year in what has already been documented as the hottest decade on record both in the United States and worldwide. This makes a good setting for discussing global climate change, a much better setting than, say, the second week of a record-setting cold spell in February, 1999 when some climate change conferences were held, when one wondered if the locals might turn out at any moment carrying signs reading "Welcome Global Warming."

My comments focus on the planting of forest trees to sequester carbon dioxide, the primary greenhouse gas contributing to global climate change. This focus on tree planting is consistent with the Kyoto Protocol of December 1997, which gave emphasis to land-use changes—especially the extent and condition of forests—and to afforestation and reforestation, which are topics of particular interest to all of us concerned with nursery management.

I am addressing 2 concepts for your consideration. First, tree planting for climate change has the potential to become much larger than any prior tree planting program. Second, as nursery managers, you may have insights and data that could advance the understanding of the probable impacts of climate change on our forest resources.

CARBON IS OKAY

The carbon atom is the basic building block of life, as we know it on Earth. All living things contain carbon, so we can say that,

Life = f (carbon)

That is, life is a function of carbon.

Because carbon is a basic element, its amount in the universe is constant. The problem, then, is neither carbon nor its amount, but where and how it is found: there is simply too much carbon in the atmosphere in the form of carbon dioxide (CO_2).

ATMOSPHERIC CARBON IS CLEARLY ON THE INCREASE

From 800 to 1,800, the concentration of CO_2 in the atmosphere stayed within the range of 275 to 285 parts per million on a volume basis (ppmv). This was known, but not given much attention, even as late as the 1960s. It was widely believed that world's carbon was in balance. This was sometimes described, in simple terms, as an equation with the green plants on one side and animals on the other. Green plants with their gift of photosynthesis take in CO_2 and emit oxygen (O_2), while the animals require O_2 and emit CO_2. Meanwhile, the oceans in their vast expanse, covering 70% of the Earth's surface, act as a buffer with a two-way exchange, either taking in or releasing CO_2 depending on the temperature of the surface waters and the relative concentration of CO_2 in the water and in the atmosphere.

Interestingly, green plants also require O_2 and emit CO_2 through respiration, as they draw upon their reserves of carbon-rich sugars and starches created during photosynthesis, for growth and other essential processes. Trees are net emitters of CO_2 whenever the rate of photosynthesis falls below the rate of respiration, as commonly occurs

during seasonal dormancy, at night, and even during extended periods of overcast days during the growing season. Tree roots also require O_2 and release CO_2.

Fortunately, the O_2 requirement of healthy, growing trees is small compared to their production of oxygen and intake of CO_2, and the surplus carbon taken in is stored in the tree's roots, stem, branches, and foliage. Approximately one-fourth of the live (green) weight of wood and one-half of the dry weight of wood is solid carbon.

In 1956 meteorologists at Mauna Loa, Hawaii documented readings of atmospheric CO_2 that were consistently above the normal range. Actually, this had been going on for some time, and data from other stations in both the northern and southern hemispheres confirmed that CO_2 levels had been rising since the advent of the industrial age and the attendant increased consumption of fossil fuels. By the mid-1990s CO_2 levels were at 360 ppmv and still rising.

There is no serious debate among scientists about the increased concentration of atmospheric CO_2. What this means in terms of changes in the climate, however, is more contentious. Notwithstanding, the Intergovernmental Panel on Climate Change (IPCC) has cautioned that there is evidence of a discernable human influence on global climate. This, in turn, has led to the call for concerted international action with a major role assigned to forestry since at least 1989. (See "Forestry in United States Climate Change Action Plans: "From the Arch to Kyoto" in suggested readings section.)

Climate Change Impacts

The IPCC has estimated that the average global temperature has increased by 0.5 to 0.8 °C (about 1 to 1.5 °F) from the beginning of the industrial revolution in 1880 to the present and that temperature is likely to increase by another 3 °C with an error of plus or minus 1.5 °C (a range of 2.7 to 8.1 °F) sometime in the next century as the level of atmospheric CO_2 doubles over current readings. An increase in temperature of this magnitude has never been witnessed during the span of human existence, nor have scientists been able to reconstruct from historic evidence that a temperature increase of this magnitude has ever occurred. It is known, however, that the last Ice Age was caused by a drop in temperature of only 2 °C (3.6 °F).

Early speculation that the Earth is on a doomsday path with the oceans rising hundreds of feet and the occurrence of other catastrophic events have moderated, and, in fact, there may even be some benefits associated with climate change. The general consensus today is that temperatures near the equator will change little, but temperatures will rise in the temperate and boreal zones. Mean sea level may increase by 15 cm to 95 cm (6 to 37 in), due mainly to thermal expansion of sea water, and there will be an increase in floods, droughts, wildfire, and infectious diseases.

At greatest risk are people in the poorest nations and natural ecosystems. Much of the world's human population and associated infrastructure is located in low-lying coastal areas. Coping with coastal flooding and other climate-induced events would be costly but possible in the United States and other wealthy nations, but nearly impossible in many of the poor nations.

Natural ecosystems at greatest risk are those already under stress and those with limited mobility and few suitable alternative locations. Coral reefs, coastal wetlands, and maritime forests could be extensively damaged, as could alpine and subalpine forests.

Recent studies suggest that Great Lakes shipping could benefit from an extended ice-free shipping season due to warming in the United States and Canada. Production may also be increased in agriculture and forestry in these countries, due to a longer growing season and increased rates of crop and tree growth in a CO_2 enhanced environment. The Corn Belt could move northward toward Canada, and over time tree species would also shift to the north.

One positive effect of the concern over climate change has been the great expansion of research in the physical sciences. Exciting work is being done at an accelerated pace on weather systems, ocean currents, carbon in agricultural soils, and forestry to name but a few areas of study. Climate change research is in its infancy, and much is yet to be learned. It is in this context that I invite members of the tree improvement and nursery profession to consider how their special knowledge could contribute to a greater understanding of how different climate change scenarios could impact our forests.

Current forest research on the adaptation of forest communities to climate change has focused largely on how changes in CO_2, temperature, and moisture affect the growth and vigor of existing trees in various age classes. This is important and critical work, but I would like to see the experts in tree improvement and nursery science move ahead to the next phase and look at the immediate and long-term effects of these climate variables on the life cycle of trees during highly critical periods, such as flower and fruit setting and germination. Here are 2 examples:

"We know that many forest trees do not produce good crops of seeds every year; instead, a good seed crop tends to occur every other year, or perhaps, only once in every 3 to 5 years, and that the best seed years are associated with alternating crisp cool nights and warm sunny days. But a likely consequence of climate change will be warmer nights, due to an increase in low clouds, and fewer cloudless days.

Certain species of trees have chill requirements for fruit setting and seed germination. What would be the consequences of warmer and shorter winter seasons?"

Climate change models cannot yet give forecasts of weather conditions for specific regions or local areas. But likely scenarios can be developed to reflect a range of different conditions. With specific knowledge and records (for example, annual seed production in orchards), it should be possible to determine some of the probable consequences of climate change on natural stands and on seed orchards. Would it become prudent to relocate or expand the size of seed orchards and to gather and store more seeds during good seed years? Nurseries use refrigeration to stratify seeds, and in this respect, are not dependent upon nature, but might there be other problems? Alternatively, it may be found that forests are highly resilient and few significant problems are likely to occur. If so, this would be an important finding to document.

The Dual Role of Forests

The United States Geological Survey estimates that on a worldwide basis the destruction of forests through deforestation—mainly in the form of land clearing for agriculture in the tropical countries—annually releases about 30% as much CO_2 as, and is second only to, the burning of fossil fuels.

In contrast to the world situation, the forests in the United States are relatively young, following the occurrence of extensive logging at the turn of the last century and continued logging since then and, on the whole, have been increasing in wood volume and other biomass and, hence, in the amount of carbon stored. Birdsey and Heath of the Northeastern Forest Experiment Station estimate that, for the period 1950 to 1990, United States forests added an average of 309 million tons of carbon per year, enough to offset 25% of our CO_2 emissions from the burning of fossil fuels. They estimate, further, that for the 1991 to 2040 period, United States forests will offset 202 million tons of carbon per year, or 15% of projected US fossil fuel emissions.

Tree Planting to Sequester Carbon

More than a dozen forestry related options to reduce CO_2 emissions and to increase the storage of carbon in forests (sinks) have been proposed (Table 1). Several of these actions are already being implemented and others may become commonplace, simply because reducing United States emissions to a level 7% below 1990 levels—as currently called for in the Kyoto Protocol—through the reduction in fossil fuel emissions alone, is unrealistic. Transportation, electric power generation, manufacturing, farming, our homes, and our very life styles are based on the use of fossil fuels, and this cannot be rapidly nor radically changed without causing major disruptions.

The planting of forest trees to increase the extent of forests and growth of biomass on poorly stocked existing forest land was recognized in the Kyoto Protocol developed by the international community in Japan in 1997. If this protocol is ratified by the United States Senate, it will attain treaty status and become a legally mandated, national commitment.

Tree planting is a well-established technology. Currently, about 2.5 million acres are planted annually using over 1.6 billion trees. Most tree planting (almost 90%) occurs on private sector lands: companies in the forest industry and nonindustrial private landowners each planted over 1 million acres in 1997. Forest carbon projects can be undertaken on all ownerships, but

Table 1. Forestry Options to Reduce Emissions or Enhance Sinks

1. Reduce conversions of forests to other land uses (deforestation)
2. Increase afforestation
3. Increase reforestation
4. Reduce timber harvesting
5. Improve logging techniques to avoid damage and losses to residual growing stock
6. Reduce wildfire losses
7. Reduce energy use in growing, harvesting, and processing
8. Increase recycling of wood and wood products
9. Replace fossil fuels with biomass for energy (short rotation woody crops, residues)
10. Extend the life of forest products (improved design, better preservative treatments)
11. Substitute wood for more energy-intensive products, like steel and concrete
12. Increase agro-forestry
13. Increase the planting and care of urban trees

Source: Moulton 1998

nonindustrial private owners almost certainly will be in the forefront, as they own the agricultural land suitable for afforestation and, by far, the greatest share of forest lands in need of reforestation.

As shown in Figure 1, tree planting in the United States has increased from less than one-half million acres in 1950 to 2.5 million acres annually in recent years. Two peak periods of planting have occurred during this period. The first is the Soil Bank Program (1956 to 61), during which 2.2 million acres were planted, and the Conservation Reserve Program, which added another 2.2 million acres during 1986 through 1989 and a total of 2.8 million acres to date. These programs, as well as tree planting on private lands through the Forestry Incentives Program (FIP) and the Stewardship Incentive Program (SIP), have given us experience in delivering federal tree planting programs on private ownership. We know what incentives are required to attract private landowners to participate and have proven the effectiveness of delivering Federal forestry programs through the State Forestry agencies, and we have a solid infrastructure of public and private nurseries, tree planting vendors, and consulting foresters available to get the job done.

Curbing emissions and sequestering enough CO_2 to bring our emissions down to 7% below 1990 levels will be an immense undertaking, requiring tree planting on a scale far exceeding the programs of the past: doubling annual tree planting to 5 million acres over a 5 year period and keeping it there for at least 10 years to add 20 million acres of additional planting may be required. Whether this ever occurs, and the actual extent of a forest carbon program, depends on many factors, including whether there are any major breakthroughs in the science of climate change, whether international agreement can be reached on carbon trading between nations, and how zcarbon stocks are to be measured in existing forests and in any new projects.

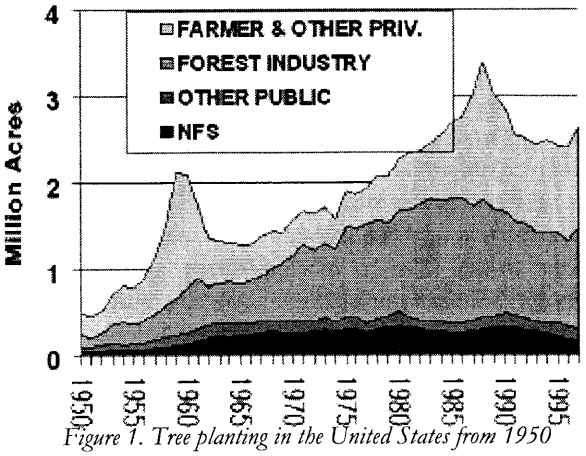


Figure 1. Tree planting in the United States from 1950 to 1997.

Concluding Comments

Tree planting for global climate change has the potential to be large—indeed, very large. And members of nursery associations will be in the midst of it all, trying as always to forecast tree stock needs 1 to 4 years into the future.

I also encourage you to consider, as mentioned earlier, how changes in climate may affect our forest trees during critical life stages, such as during seed formation and during germination. The variability associated with climate changes should be used to update current thoughts on tree planting and nursery management.

Suggested Online Readings

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ROOT PRODUCTION METHOD SYSTEM

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Lovelace, W. 2002. Root Production Method System. In: Dumroese, R.K.; Riley, L.E.; Landis, T.D., technical coordinators. National Proceedings: Forest and Conservation Nursery Associations—1999, 2000, and 2001. Proceedings RMRS-P-24. Ogden, UT: USDA Forest Service, Rocky Mountain Research Station: 20-21. Available at: http://www.fcnanet.org/proceedings/1999/lovelace.pdf

Abstract

The RPM system (Root Production Method) is a multistep production system of container tree production that places primary emphasis on the root system because the root system ultimately determines the tree's survival and performance in its outplanted environment. This particular container production system has been developed to facilitate volume production, in a high-quality tree with good height-caliper balance. Approximately 80% of our production consists of native trees, many of which present transplanting difficulties using conventional nursery growing systems. We specialize in oak production, currently growing 26 varieties.

Key Words

Oak production, container nursery

SEED SELECTION, COLLECTING, PROCESSING AND GRADING

Superior trees growing on specific sites are selected for seed collection. Experience has taught us that most species have ecotypes that are site specific. We look towards the wetlands or floodplains as a prime seed source for native tree species that are found growing on both wetland and upland sites. Since they have evolved under stress we find they will consistently outperform their upland counterparts on virtually any site, particularly on highly stressed sites.

After basic cleaning and drying procedures are completed, all seeds are graded and sized using aspirators or gravity tables. We find the weight of individual seeds to be more important than size; thus air separations that use specific gravity give the best results. This step is the first "grading," but it is of great importance in our steps to produce uniformity.

Step I—Seeding, Timing, Stratification, and First Root Pruning

Seed are placed in a bottomless mesh flat measuring 18.5 by 14.5 by 2.5 inches deep with mesh spacings of 0.375 inch. Our standard growing medium consists of 40% composted rice hulls, 40% pine bark, 20% sand plus slow release fertilizer, micronutrients, and a wetting agent. The medium is also inoculated with mycorrhizae spores. Air space is of utmost importance in this step. This media mix provides between 35% and 40% air space. Seeded flats requiring stratification are stacked on pallets, wrapped in polyethylene, and placed in cold storage at 34 °F (1 °C).

Timing and type of stratification become most important because production timing requires moving seeded, stratified flats to heated greenhouses February 1st to begin germination. The first air root pruning is done during February so that grading, selection and transplanting can be done approximately March 1st. The purpose of the shallow root pruning to approximately 1.5 to 2.0 inches depth is to force first lateral roots higher on the root collar. Since most tree roots are just under the soil surface, we find this technique to benefit all species. This is of extreme importance for wetland plantings where air becomes a critical factor in survival and future growth. This also allows for more even distribution of roots when containerized, which is one of the prime objections of shallow root pruning.

Step II—Grading, Selection, Transplanting to Bottomless Band

On approximately March first, when seedlings have made their initial first flush of growth, plants are carefully graded, selected, and transplanted to a plastic, square bottomless band. Particular attention is given to height, caliper, and root development. In most species, the top 50% is used and the remainder is discarded. A standard plastic bottomless band measuring 2.875 by 2.875 by 5.5 inches has been shortened to 3.75 inches in depth. The shorter band gives us comparable growth and improves the root distribution in the production container. Transplanted seedling bands are placed on bottomless benches for approximately 60 days where additional air pruning occurs on the secondary lateral roots, further enhancing development of a shallow root system. These first 2 steps are timed so that the bands are ready to go outside to the container production area the first of May, avoiding late frosts and freezes.

Step III—Hardening Off to Marketing Size

Flats holding 36 tree bands are moved from greenhouses on 4-by 6-ft pallets and placed outdoors in full sun for hardening off for 48 hours. During this hardening period they are misted intermittently to relieve stress. After 2 days (48 hours), the pallets are moved to container production areas where they are dibbled into existing prefilled containers. A shallow growing container is preferred, realizing that most of the feeder roots will always remain in the upper 6 to 8 inches of soil after the tree is outplanted. Our standard growing container is a squat container measuring 10 inches across and 7 inches in depth. This 2.5-gallon container allows more root mass to develop laterally. This system allows us to finish most native species to marketable size in 1 growing season or approximately 210 days from germination.

Summary

RPM system, a multistep tree growing program using seed selection and handling, 2 steps of air root pruning, and careful production planning can produce container-grown tree liners that are uniform in grade and quality. Air root pruning at a shallow depth ensures more feeder roots higher on the root collar, providing better air uptake, faster growth, and near-perfect survival after transplanting to final growing sites. RPM results in uniform top growth, and in most cases this uniformity persists. This is important in plantings where repetition is desired. Seedlings provide a broad genetic base, which will ensure longevity and protection against diseases and conditions that might endanger certain asexually produced and over-used varieties.

Using Soil Test Results to Determine Fertilizer Applications

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Key Words

Bareroot nursery, fertilization, soil management, nutrient balance

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Using soil test results is a very useful practice

IF the sample(s) of soil are good representations of the nursery soil. The lab results can be no more accurate than the samples submitted, and

IF you know the texture of the nursery soil, and

IF you know which soil extractant was used by the lab, and

IF you know what crop is to be grown, and

IF, for trees, which species is to be grown and whether it will be 1+0s, 2+0s, 3+0s, 2+1s, 2+2s, 3+2s, plug-1s, etc., and

IF, for a cover crop, whether summer or winter crop, turned under green, turned under mature, harvested and straw turned under, harvested and straw bailed, and whether peat, sawdust, compost, or other organic material will be applied (what that material is and its rate and time of application), and

IF you know those things and all but 1 of them is under the nursery managers control

THEN, using soil test results can be very helpful in determining needed fertilizer applications.

The first and foremost practical point to consider is the lab that actually runs the soil tests. In the South, it became imperative to select 1 common lab because there are more than 40 nurseries participating in a soil analysis interpretation project. Otherwise, the resulting collection of analyses would have been extremely confusing. Here are the reasons why:

1. Different labs use any of several extracting solutions. Some extract only a few nutrients and others extract a wider range. None of them get all nutrients needed by trees. Common extractants used include:

   Bray 1® or Bray 2® (developed in Illinois)

   Truog® (developed in Wisconsin)

   Mehlich 1®, 2®, and 3®—(developed in North Carolina).

   Mehlich 1 is also referred to as the double acid extractant.

   Olsen®—(developed in Colorado)

   Others include, Morgan, 1 N ammonium acetate, buffered at some specific pH value or not buffered, and hot water.

2. Acidity (pH value) may be determined in water or in 1 N KCl.

   These values are always different by at least 1/2 pH unit.

3. Some labs do not run tests for boron (B) because B-deficient soils are mostly either of volcanic origin (not many nurseries in North America are in this category), are low in organic matter, or are sandy soils. Many nursery soils are B-deficient, but most agricultural soils are not. Thus, despite agricultural soils lack of need for this test, we really need to test the B level in many of our nursery soils.

4. There are 3 common methods for determining soil organic matter, and each will give very different results for the same

sample. Thus, in order to correctly interpret the results, you must know which method was used. These methods are loss-on-ignition, acid hydrolysis, and alkaline hydrolysis.

5. Numerous labs report available iron (Fe). Testing for this element is almost useless as far as nursery soils are concerned. Iron nutrition of seedlings is strongly affected by weather and species of tree being grown, and only slightly by soil availability. Most nursery soils contain ample Fe, yet Fe deficiency is very common.
6. Probably the most universally needed nutrient in tree nurseries is nitrogen (N) and yet there is no useful test for available N. Several labs do run extractable ammonium and nitrate tests. These results are only marginally useful, however, because those N sources are very dynamic in the soil and their test values vary from day-to-day. They represent a snapshot of soil N at one point in time and have very little value in terms of a whole growing season. As far as N supply and dynamics go, we rely more on tissue analysis and history than on soil testing.
7. Finally, and most confusing, labs vary greatly in how they present the results of their analyses. Acidity (pH value) and organic matter (%) are pretty standard. Beyond these 2, there is too much variability. We find results expressed as pounds per acre, kilograms per hectare, parts per million, milliequivalents per 100 grams, and as index values.

Each lab feels fully justified in using the methods and expressions of results employed. To get the maximum benefit from soil test data, a nursery manager almost needs an interpreter.

In medicine, it is said that diagnosis should precede prescription. The same is true in prescribing soil management operations in a nursery. Soil tests provide the diagnosis. We must prepare the prescription.

Before prescribing, we need to establish a set of levels for available nutrients, acidity, organic matter level, etc., for each crop that will be grown. This can only be done after we have decided on the laboratory that will run the soil analyses and we have learned the methods of analysis that they will use. In the South, despite the fact that we have not changed labs in over 15 years, the standards sheets have had to be rewritten twice. The lab changed the extracting solution both times. In both cases, the change was to an extracting solution that was better-suited to forest nursery soils than the preceding one. Currently, that lab is using Mehlich 3, which is excellent for nursery soils and determines the maximum number of nutrients.

Water

Very few nurseries are irrigated with distilled water. Thus, we need to be able to adjust our calculations to account for nutrients that are applied in the irrigation water. The most common problem encountered is that a calcitic limestone aquifer is tapped for water. This is almost guaranteed to apply an imbalanced amount of calcium (Ca) and magnesium (Mg). The ideal is to have about 4 parts of Ca for each 1 part of Mg in the soil. This is recorded as a Ca/Mg ratio of 4. Mother Nature gives us a bit of a break by tolerating a range of Ca/Mg ratios from about 1 (equal amounts of Ca and Mg) to 10 (ten times as much Ca as Mg). Once you get outside that spread, however, you have a problem that demands attention. Most commonly, the irrigation water provides Ca at much more than 10 times the amount of Mg. Since we cannot subtract Ca from the soil, we frequently must add Mg, even though on an absolute basis there is already an adequate supply of Mg. In this case, the ratio is at least as important as the absolute values. If the Ca/Mg ratio exceeds 10, there is a real likelihood of a lack of chlorophyll formation. This results in poor growth and a general chlorosis. Often, people will see these symptoms and respond by adding more N. They are then bewildered because addition of N does not eliminate the chlorosis, not realizing that a shortage of N is not the problem.

There are other problems that may be related to the irrigation water. Some aquifers contain considerable Na. This tends to do 2 things. First, it raises the pH value of the water and sometimes that of the soil as well. Second, Na will antagonize the uptake of potassium (K). Sodium also tends to enhance crust formation at the soil surface. This is caused by the defloculation of clays in the soil. In addition, many of the internal pores in the soil become blocked, and internal drainage is seriously impaired. Irrigation water quality is only one aspect of soil fertility management. Other items critical in the management of soil fertility are

acidity, Ca, Mg, phosphorus (P), potassium (K), N, trace elements, and organic matter.

Acidity (pH value)

When you receive soil test results from a lab, the first item to look at is the pH value of the soil. Soil acidity affects many things in the soil and in the seedlings, but it mainly affects the availability of several nutrients. Thus, we want to keep the soil within a range that, for most species we grow, is not too far from pH 5.5. If we need to reduce acidity (raise the pH value) lime is added. The amount of lime needed is strongly affected by soil texture and organic matter content. For example, to raise the pH value from 5.0 to 5.5 in a medium sand with low organic matter may require no more than 0.5 ton of lime per acre. The same pH change in a silt loam with ample organic matter may easily require up to 2 tons of lime per acre. Also, we need to look at the Ca/Mg ratio to see whether we should do the pH adjustment with dolomitic or calcitic lime. Dolomitic lime provides plenty of Mg whereas calcitic lime does not. If the pH value is too high, we usually lower it with elemental sulfur (S). The amount of S needed is, again, affected by the pH change needed and the soil texture. One ratio that does stay pretty well fixed is that about 800 pounds per acre of S will provide the opposite effect on the soil pH value of 1 ton of lime (either calcite or dolomite).

Calcium

When Ca is needed but the pH value is correct, we apply gypsum (calcium sulfate). This will also provide some S. Whereas both forms of lime and S need to be applied prior to planting, gypsum is useful because of its higher solubility. It can be applied either preplant or postplant (as a topdressing).

Magnesium

Sources of Mg include Epsom salts (magnesium sulfate), magnesium nitrate, magnesium carbonate, and a product called Sul-Po-Mag®, which is a mixture of potassium and magnesium sulfates. These are all sufficiently soluble to be applied either preplant or postplant. One thing to note here is that although magnesium nitrate is a fine source of Mg, it is a poor source of N for most tree species. Douglas-fir does seem to use that N fairly well, but nearly all other species do not use it very efficiently.

Phosphorus

For many years, when phosphorus (P) was needed, it was provided prior to planting as ordinary superphosphate (OSP). Its problem was a low analysis (0-20-0). It has been mostly replaced by triple superphosphate (TSP) because of its higher analysis (0-46-0). However, there is one hidden trap in making the change from OSP to TSP. Most people were unaware that when they applied OSP, they were also applying S to the soil. In fact, OSP contains more S than P, and a need for S as a nutrient was rare. Today, we find frequent need for S. The TSP does not contain any sulfur. That is because phosphoric acid is used in its manufacture, rather than the sulfuric acid that was used in the manufacture of OSP. Finally, we must note that neither OSP nor TSP are very soluble. Thus, they must be applied preplant and disked in. Sometimes, we discover a need for P after the crop is growing. This is supplied as diammonium phosphate (DAP) because it is considerably more soluble than either OSP or TSP. The DAP has one other effect that can be very useful. Mycorrhiza development can be slow, and DAP, for some reason that is not fully understood, will provide a stimulation of mycorrhizae development. This is true regardless of the P and N supply in the soil.

Potassium

Potassium is easily provided and is about the least expensive nutrient we need. The most common source is potassium chloride (muriate of potash). A second source, which is quite useful because of the S it contains, is potassium sulfate (sulfate of potash). As mentioned earlier in our discussion of Mg, Sul-Po-Mag® supplies K, S, and Mg should there be a need for these nutrients. All of these sources are quite soluble. Thus, they can be applied either preplant or postplant. Usually, because they are so soluble, it is not wise to apply all the potassium prior to planting. One or 2 topdressings during the growing season is usually a good idea. In soils that are low in K, a late growing season topdressing is often suggested. Physiologists have told us that a good supply of potassium in late summer and early fall will help harden off the seedlings before cold weather arrives. In soils that are already well-supplied with K, the benefit of this application is understandably less pronounced.

Nitrogen

As mentioned earlier, N is always needed. Nitrogen is used by plants in either of 2 forms. When the N atom is associated with hydrogen, as in ammonium or urea, it is called "reduced." When the N atom is associated with oxygen, as in nitrate, it is called "oxidized." Most tree seedlings will use either reduced or oxidized N. But, most species are much more efficient at using reduced N. We commonly apply ammonium nitrate, which includes both and is satisfactory and reasonably economical to apply. Also, it has essentially no effect on the soil acidity. The alternative source, ammonium sulfate, is very efficiently used, and it provides some S. However, it does lower the pH value of the soil. Sometimes that is desirable and sometimes it is not. In many parts of the world outside the United States and Canada, ammonium nitrate is not available.

Formulations where all N is supplied in the nitrate form, such as magnesium nitrate, potassium nitrate, or sodium nitrate (sody), should not be used as N sources for tree seedlings. It is a waste of both time and money.

Urea is a good source of N, as long as it is promptly watered-in. When urea lies on the soil surface for only a few hours, it is likely to be broken down by enzymes that are produced by many soil microbes. The result is that ammonia gas is produced and lost into the atmosphere. That wastes both N and money. If urea is used correctly, it is fine. However, the potential for significant N loss is always present.

Beyond these 3 common sources, there is a plethora of other materials that are called "slow release" sources of N. In the right circumstances, they can be useful. Usually, their biggest problem is cost. Also, many of them do not release their N at a rate that matches the seedling needs. Basically, their convenience is frequently out-weighed by their cost and/or lack of synchronization with the seedlings' requirements.

Minor (trace) elements

These come in various forms. However, most of them are quite soluble and are principally applied to the foliage. These include sodium borate, copper sulfate (blue vitriol), manganese sulfate, and zinc sulfate. Iron (Fe) is available in sources of all sorts, but chelated forms are usually the most effective (although not always the cheapest to use). Ignoring Fe, the other trace elements provide a fairly easy-to-remember rule of thumb, as far as their needs on nursery stock. Alphabetically, they are B, Cu, Mn, and Zn, and typical rates of application are 2, 3, 4, and 5 pounds per acre, respectively. They are only applied when a soil test indicates a low supply.

Iron deficiency occurs in hot weather, regardless of soil test level. Iron availability is strongly affected by a group of soil bacteria that are called "iron-oxidizing bacteria." When active, they convert Fe into a non-available form. They become very active in warm soil and die down again in cool soil. The rate of foliar application of Fe varies with species of tree and the severity of the deficiency. Many species will respond to 1 or 2 applications of Fe at 2 pounds per acre. Some require as much as 4 applications at 4 pounds per acre. Nearly all nursery soils contain adequate Fe. The problem is availability, not quantity.

Organic matter

Cover crops or "woody" material (peat moss, to wood chips, to bark) all provide organic matter. Which do we need and why? They are all beneficial, but do different things. Woody materials provide some physical benefit, but mostly we want the lignin that the wood contains. Lignin provides cation exchange sites that hold nutrients against leaching and help hold the pH value where we want it. Cover crops (also called green manure or catch crops) help reduce wind and water erosion, catch and hold nutrients, and provide food for beneficial soil organisms. They also serve as a slow-release fertilizer. They release nutrients as they decompose. Woody materials last in the soil from 2 to several years. Cover crops do not increase the soil organic matter content significantly, except for a few weeks or months. Their rate of decomposition is rapid.

How much organic matter do we need in the nursery soil? First, we need to note that the soil organic matter "equilibrium level" depends principally on climate and soil texture. In Pacific Northwest nurseries, it is common to find 5% to 8% organic matter. In the deep South, 1% to 2% is about all that can be maintained with the same effort. The microbes hardly slow down in the continuously warm soils of the South. In the North Central region, because of cold winters, soils come closer to a 3% to 5% equilibrium level.

Other Soil Properties

Physical and biological properties of soil are also important in the growth of quality stock. However, they are not included in soil testing. Consequently, we will merely mention that they can have significant effects that are either positive or negative on the seedlings response to nutrient additions.

Summary

When used correctly, soil testing will provide the diagnostic information needed for efficient management of soil fertility, acidity, and organic matter content. It will increase the efficiency of fertilization and produce a high percentage of grade one seedlings. The most important need at this time is to determine the appropriate levels for nutrients, acidity, and organic matter for each tree species we plan to grow.

Fertilizer Application Equipment for Bareroot and Container Nurseries

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Key Words

Broadcast spreader, seed drill, fertigation, fertilizer injection

Fertilizer application equipment can apply chemicals in dry or liquid form or as manure. The appropriate equipment will place the material at the desired rate in the desired location. In bareroot nurseries, fertilizer is usually applied dry in granulated pellets or coated form. Where in plentiful supply, animal manure may be used, both for nutrients and organic matter. In container production, nutrients may be applied in granular slow-release form or, more commonly, injected into the irrigation water supply.

Application Equipment for Dry Chemicals

Drop-Type Fertilizer Distributor

Tractor mounted and trailer machines are available. Hand-pushed distributors are used for small beds. The hopper has a V-bottom with agitator and adjustable gates that control the rate of flow through the holes. Hopper widths are available from 2 to 12 feet and spread the fertilizer over the bed.

Broadcast Spreader

This is also called a spin or cyclone spreader. The fertilizer hopper can be trailer or tractor mounted. Hand-operated machines are also available. Fertilizer is distributed by 1 or 2 spinning disks located below the hopper and powered by the tractor or a set of drive wheels. Application rate is controlled by a slide gate. Ground coverage is greater than with the drop-type distributor, but uniformity is not as good.

Seed Drills

This equipment can be fitted with fertilizer hoppers that apply chemicals at the same time seeding is done. Metering devices include the star wheel, feed roll, wire worm, or auger. Drop tubes direct the fertilizer into the same furrow as the seed. Liquid fertilizer can also be injected into the soil.

Individual Pot Applicators

This drop-type applicator feeds small quantities into individual containers. The hopper holds a quantity of fertilizer that can be conveniently carried. A measuring device meters the chemical and drops it into the pot. Several thousand pots can be fed per hour.

Incorporation of Fertilizer into Growing Media

For batch mixing, granular fertilizer can be dumped into the mixer along with other components before mixing. For continuous mixing, a fertilizer dispenser meters the chemical onto the conveyor belt before components reach the mixing unit.

Selecting an Applicator

The size of the nursery influences applicator selection. A large machine may be too expensive to own and difficult to maneuver in small areas. A small machine may require frequent stops for refilling.

Drop or broadcast spreaders take less power than drills. Stony soil is less of a problem.

Placement of the fertilizer can affect the growth of the crop. Fertilizer placed on top of the soil may take time before it reaches the root system.

Fertilizer applicators are heavy when full. Flotation tires may be a good investment especially if the application is made when the soil is wet.

If you already have a tractor, you may want to size the machine to fit it. Some manufacturers list horsepower requirements for their machines.

Because fertilizers are corrosive, many modern applicators have stainless steel or plastic parts. Machines should be cleaned after each use.

Ease of calibration is important to get accurate application and to avoid the cost of overfertilization. It should be done with each change of fertilizer material. Follow the instruction manual to make the correct adjustments. The rate of fertilization is found by collecting the material over a known area.

Manure Spreading Equipment

Animal manure can add nutrients and organic matter to the soil. It can be handled as a solid, semisolid, or liquid. The amount of water and bedding influence its form. Horse, sheep and poultry manure are usually solid. Depending on the type of housing, dairy and swine manure may be any of the 3 forms.

Selection of a spreader should be based on the type of manure available and the size of the nursery. The 3 most common types are box-type, flail, and tank spreaders.

Box-type Manure Spreader

The size of the spreader is usually designated by what volume in cubic feet that the box will hold. The power needed to drive the apron chain comes from either the tractor PTO or the spreader wheels. The rate of feed and the speed of the beaters is usually variable. This type of spreader can also be used for the application of compost or mulch materials.

Flail Spreader

This spreader consists of a horizontal liquid-tight tank mounted on wheels. It is designed to handle solid or semisolid manure. Flail chains on a powered horizontal shaft throw the manure out by centrifugal force. A uniform spreading width of up to 20 feet can be achieved.

Tank Spreader

Where liquid manure (less than 10% solids) is available, it is usually loaded with a pump and spread with a tank spreader. The spreader can be either trailer mounted and pulled with a tractor or truck mounted. The liquid flows to the rear of the tank where it flows onto a spinner for spreading. Tanks with capacities of 1,000 to 5,000 gallons are available.

Fertigation

Fertigation is the controlled feeding of nutrients to plants through the irrigation system. Application of fertilizer through the water system has several advantages:

1. Easy adjustment of nutrients, depending on crop needs.
2. Nutrients become available to the plants quicker.
3. More accurate placement of fertilizer.
4. Less fertilizer needed.
5. Reduced labor to apply fertilizer.

Irrigation can be done with many systems; 4 are described here.

Overhead

Lateral supply lines feed sprinklers that produce a circular pattern for outdoor plants in the nursery or for seedlings growing in a greenhouse. To be effective, a pattern of at least 60% overlap is needed to get uniform coverage.

Boom Irrigator

Equipment for applying irrigation water with a boom that travels over the growing area is available for both outdoor and greenhouse production. This system is the best method for watering plug and cell trays, as very uniform application can be made. Both hand operated and computer-controlled booms are available.

Drip Irrigation

Improvements in drippers have made this system viable for beds and larger containers, which results in considerable savings in water and nutrients. Clean water is required. Pressure compensating drippers are required for sloping beds to get uniform distribution. High-output drippers are now available for quicker application of water and less clogging.

Capillary Systems

Mats, trays, benches, and flooded floors are systems where the nutrient solution is absorbed by the growing media from underneath the container. These systems work best with small containers and plug trays.

Fertigation Equipment

Venturi Suction Device

The simplest low cost devices use the Venturi principle to create a pressure differential between the container holding the fertilizer solution and the water line. As water passes through the restricted area of the injector, the velocity is increased, creating a vacuum. A small tube connected at this point allows the fertilizer concentrate solution to be siphoned into the water stream and mixed before reaching the plants. The fixed-dilution ratio will vary somewhat with water pressure differences and hose length.

Bladder Tank

These units use a pressurized tank attached to the irrigation line in two places. A control valve achieves a pressure differential between the inlet and outlet. Inside the tank, a plastic bag (the bladder) holds the fertilizer solution. Water from the supply line surrounds the bag forcing the solution through a metering valve into the water supply. The bladder improves the uniformity of discharge. The rate of fertilizer injection can be regulated to some degree by varying the pressure. There are no moving parts and the bag can be replaced easily.

Water Motor Controlled Injector

Water motor-driven proportioning injectors use water flow to operate a piston or diaphragm to inject or force fertilizer into the water stream by positive displacement. As water flows through the injector, the water causes a cam to turn and push a piston back and forth. This equipment gives consistent feeding ratios at specific flow rates over a wide range of pressures. Water motor injectors usually decrease line pressure more than water meter styles.

Water Meter Controlled Injector

These injectors use a water meter mechanism to determine flow rate and a water or electric powered diaphragm pump to inject the fertilizer. They can be purchased with several heads attached to the same motor so that more than 1 nutrient can be fed at the same time.

Selecting an Injector

All types of injectors can be successfully incorporated into a greenhouse or outdoor irrigation system. The following factors should be considered when making a selection.

The injector must be compatible with the water flow rate in gallons per minute. Most injectors have a range of flow over which they will operate. Select one that will allow for some expansion should a different irrigation system be installed, but don't oversize it, as larger injectors may not work when 1 hose is turned on.

Except for the Venturi type, all injectors have variable dilution ratios. This is desirable, as available concentrations or the size of the mixing tank may require different ratios. Check on the ease of changing the ratio.

Injectors with an integral mixing tank are available in several sizes. A separate concentrate supply is needed for most injectors. A 5-gallon pail is adequate for 1 hoophouse. Larger plastic or concrete tanks can also be used. Select a tank large enough to feed a single greenhouse or several zones to reduce frequency of refilling. In larger ranges, nutrient concentrate may be distributed from a central tank throughout the range in PVC pipe. Agitation within the tank is important to maintain a uniform solution.

Fixed units are used in small operations or where all irrigation water is piped to the greenhouses. Portable units can be moved from one area to another.

Multiple injector units are required where more than 1 chemical is applied at the same time. They are also used where individual nutrient levels are monitored by a computer.

Check the specifications for the amount of pressure loss caused by the injector. Some units lose as much as 15 psi. For some water systems, this may limit the amount of hoses or number of zones that can be operated at one time. Also, be sure that piping is large enough to keep pressure loss to a minimum.

For large operations, an injector that can be integrated into the computer system is desirable.

Sensors, pumps, and water meter should be compatible with the software.

Check to see if the injector is compatible with the chemicals that you will be applying. Water should also be clean to avoid wear. Most manufacturers recommend that a 200 mesh filter be inserted before the injector.

Safety devices should be installed in the system to prevent backflow into the water source. A backflow preventer is required on all systems connected to potable water. A check valve should be installed in the chemical injection supply line. An interlock should be installed to prevent an electrical injector pump from operating if the water flow stops. Repair parts and dependable service should be available locally.

Injector operation must be checked frequently and calibrated to ensure proper operation and application rate. Follow the manufacturer's recommendations for calibration.

Additional information is covered in the booklet, "Fertilizer and Manure Application Equipment" —NRAES-57, available for $6.00 from the NRME Dept., UConn, Storrs, CT 06269-4087. Make check payable to UConn.

DOUGLAS-FIR CONTAINER STOCK GROWN WITH FERTILIZER-AMENDED MEDIA: SOME PRELIMINARY RESULTS

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Key Words

Controlled-release fertilizer, fertilizer incorporation, fertilizer treatments, outplanting performance

Incorporating fertilizer directly into the container growing media is a very new practice. Previously, it was believed that such a practice would result in toxicity due to direct contact with the root system and/or over fertilization. However, with the improved technology for controlled-release fertilizer, there is renewed interest in this practice. The objective of this study is to quantify the seedling response to various fertilizer treatments as compared to unfertilized seedlings and plug+1 seedlings.

MATERIALS AND METHODS

Container-grown Douglas-fir (*Pseudotsuga menziesii* Mirb. Franco) seedlings were grown in 1997 at The Timber Company nursery (Cottage Grove, OR). Seedlings were grown under standard nursery practices with the exception of the fertilizer in the media. Transplant seedlings (plug+1) were sown in 1996 at The Timber Company nursery and then transplanted at the Lewis River Reforestation nursery. Although sown in different years, container-grown and transplant seedlings are from approximately the same seedlot.

The effects of four fertilizers (Simplot's 13-13-13 and 17-5-11; Scotts Company's 18-5-12 and 15-9-10) which were mixed in the container media are being evaluated on styro-20 stocktype (20 in^3 cavity size). In addition, unfertilized styro-20 and P+1 transplant stock were included. Seedlings were outplanted on January 9, 1998 at a site near Siletz, OR. The study was installed in a completely randomized block design with four replications. An additional study (reported elsewhere) was installed to assess styro-8 and styro-15 seedling stocktypes as well.

Initial field height and stem diameter were measured and recorded on each seedling prior to budbreak. At the end of the first and second growing seasons (August 18, 1998 and August 20, 1999) seedlings were again measured for survival, height and stem diameter. Instances of browsing, chlorosis, frost damage, multiple tops, dead tops, and browning were also recorded. Seasonal growth was calculated by subtracting height values. In addition, foliar samples from two seedlings per treatment in each block were collected at the end of each season, dried, weighed, and composited for nutrient analyses.

RESULTS

Initial morphology showed significant differences among treatments at the time of planting (Table 1). Stem diameter of unfertilized control seedlings was significantly smaller than the fertilized treatments. Initial height was more variable, but Scotts 18-5-12 seedlings tended to be the tallest.

After two growing seasons, the fertilized plug trees at the Toledo site had significantly greater field performance than the unfertilized controls (Table 1). Fertilized trees had up to twice the height growth of the control seedlings during the first season and continued to have significantly greater growth than the controls during the second season. The Scotts 18-5-12 seedlings had significantly more height and stem diameter growth than any of the other treatments and by the end of the second season, mean height and stem diameter for seedlings in that treatment were 33% and 38% greater, respectively than the unfertilized controls. Mean height and stem diameter of seedlings from the other fertilized treatments were 20 to 22% and 17 to 23% greater, respectively than the controls (Table 1).

Transplant seedlings did very poorly compared to all other treatments. In fact, despite initial stem diameter of the transplant seedlings being significantly greater than the styro-20 seedlings, the mean stem diameter of transplant seedlings was the smallest after two seasons of growth (Table 1).

Foliar nutrient concentrations did not differ meaningfully at the end of the first season (data not shown). Nitrogen concentrations did not differ significantly among treatments. Controls tended to have the highest concentrations of P, K, B, Cu, Zn, and Mn which is most likely due to the lower growth rate of unfertilized seedlings. Foliar dry weight of fertilized seedlings was much greater than unfertilized styro-20 or plug+1 seedlings. As a result, the nutrient contents for fertilized seedlings tended to be higher than that of the unfertilized seedlings despite a lack of difference among concentrations. Nutrient data for the second season samples are not yet available.

Field performance will continue to be assessed annually and data will be reported in the literature.

Table 1. Mean field morphology at Toledo site. Within a column, means followed by the same letter are not statistically different at $\alpha \leq 0.05$. (Note: all styro-20 seedlings except plug+1 unfertilized transplant seedlings).

	Height (cm)					Stem Diameter (mm)					
Treatment	March 1998 initial height	Growth 1998	Growth 1999	Total Growth	August 1999 total	March 1998 initial diameter	Growth 1998	Growth 1999	Total Growth	August 1999 total	Survival (%)
None (control)	40.9 ab	19.7 b	48.1 a	67.9 a	108.7 a	4.8 a	4.0 b	8.3 a	12.3 b	17.1 a	99
Simplot 13-13-13	41.2 ab	34.6 c	57.3 bc	91.2 b	132.3 b	5.7 b	6.3 c	9.0 a	15.3 c	21.0 b	100
Simplot 17-5-11	39.3 a	33.7 c	59.2 bc	91.6 b	130.9 b	5.7 b	6.5 c	8.6 a	15.0 c	20.6 b	99
Scotts 18-5-12	44.1 b	40.6 d	62.9 c	101.0 c	144.9 c	6.2 b	7.9 d	9.7 a	17.5 d	23.6 c	98
Scotts 15-9-10	38.1 a	36.7 c	56.0 b	91.7 b	129.9 b	5.8 b	6.0 c	8.1 a	14.2 c	20.0 b	100
plug+1 unfertilized	45.8 b	13.1 a	49.6 ab	62.0 a	108.0 a	9.2 c	1.6 a	5.8 a	7.4 a	16.6 a	100

PLANT MATERIALS FOR RIPARIAN REVEGETATION

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Abstract

Increased public awareness and concern have prompted new efforts in riparian revegetation using streambank bioengineering techniques. Planting in a riparian zone is very different than planting on upland sites. Riparian planting zones should be used to ensure that the vegetation is planted in the appropriate location so that the planting does not create more problems than was it was designed to treat. The types of plant materials used in riparian revegetation projects include: 1) dormant nonrooted hardwood cuttings which include 3 size classes: propagation cuttings, branched cuttings, and poles; and 2) nursery plants, including bareroot and small and large container stock. Each stock type has its specific purpose, use, and limitations. Many riparian plants are difficult to propagate so propagation protocols are being developed. Streambank bioengineering is relatively new in this country, and requires different types of plant types than nurseries are used to growing. The nursery industry needs to be proactive and pursue this new market for riparian stock by showing potential customers what they can produce and emphasizing native, locally-adapted plants for their area.

Key Words

Restoration, plant nurseries, plant propagation, woody plants, bareroot nursery, container nursery, native species, biodiversity

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Riparian revegetation or restoration has received much attention in the past few years. Legislation like the Clean Water Act, water standards like Total Maximum Daily Loads (TMDLs), and ecopolitical issues like the "salmon crisis" (the listing of salmon species as a threatened and endangered species) have placed new emphasis on restoring riparian function and vegetation to degraded streams. In addition, the importance of treating agricultural wastewater, urban stormwater, mining wastewater, and other polluted water before it enters our rivers and streams will increase the demand for revegetation efforts. The need to restore overgrazed rangelands in the West where riparian zones have had most of the riparian woody and herbaceous vegetation removed by years of overgrazing is a major policy issue for federal regulatory agencies. Recent large flood events in the Pacific Northwest and the central US with the resulting damage to private property along the riparian zones have prompted many agencies to reexamine flood management plans. The need to increase the vegetation along the riparian zones which in turn will decrease flood peaks has been seen as an alternative to expensive engineered treatments such as concrete, large rock, levies and dams.

Streambank bioengineering treatments have many benefits, including:

- reducing streambank erosion by reestablishing the root matrix
- reestablishing the riparian plant community
- improving fish and wildlife habitat
- providing shade on the water to maintain lower water temperatures
- increasing biodiversity of plants and animals
- improving water quality.

Filter strips, constructed wetland systems, and riparian buffer strips have also been used to treat

non-point source pollution before it enters the riparian zone (Schultz 1994).

Riparian Planting Zones

When planning a riparian revegetation project, it is critical to consider the planting zones and the hydrology for the site. For the stream types commonly treated, there are four planting zones within the riparian corridor, plus the upland zone (Bentrup and Hoag 1998, Biedenharn and others 1997).

The lowest zone is called the toe zone that extends from the streambed to the average stream water level (Figure 1). The toe zone is subject to the most stress from stream velocities and, because it is underwater for most of the year, it is very difficult to get vegetation established in this zone. It may be possible to plant emergent wetland plant species in some situations.

The bank zone is that portion of the bank from the average water elevation (top of toe zone) to the bankfull discharge elevation. This zone is usually under water for less than 6 months of the year. It is exposed frequently to erosive stream currents, ice and debris movement, wet-dry cycles, and freeze-thaw cycles. Emergent wetland plants are recommended for planting in this zone where there is low stream energy.

The overbank zone is the area that begins at the top of the bank zone and continues to two-thirds of the flood-prone elevation. This area is typically inundated during the spring runoff and storm events. High debris loads carried by runoff events and ice flows tend to be deposited in this zone. This zone is under water for less than 3 months of the year. Shrubs with flexible stems (for example, willows) and inundation tolerant herbaceous plants are recommended for planting.

The transitional zone goes from the overbank elevation to the flood-prone elevation. It will be inundated for a short period of time during higher flood events. The vegetation will include plants that are adapted to occasional short periods of inundation and drought. Trees such as cottonwoods, birch, tree species of alder, and ash

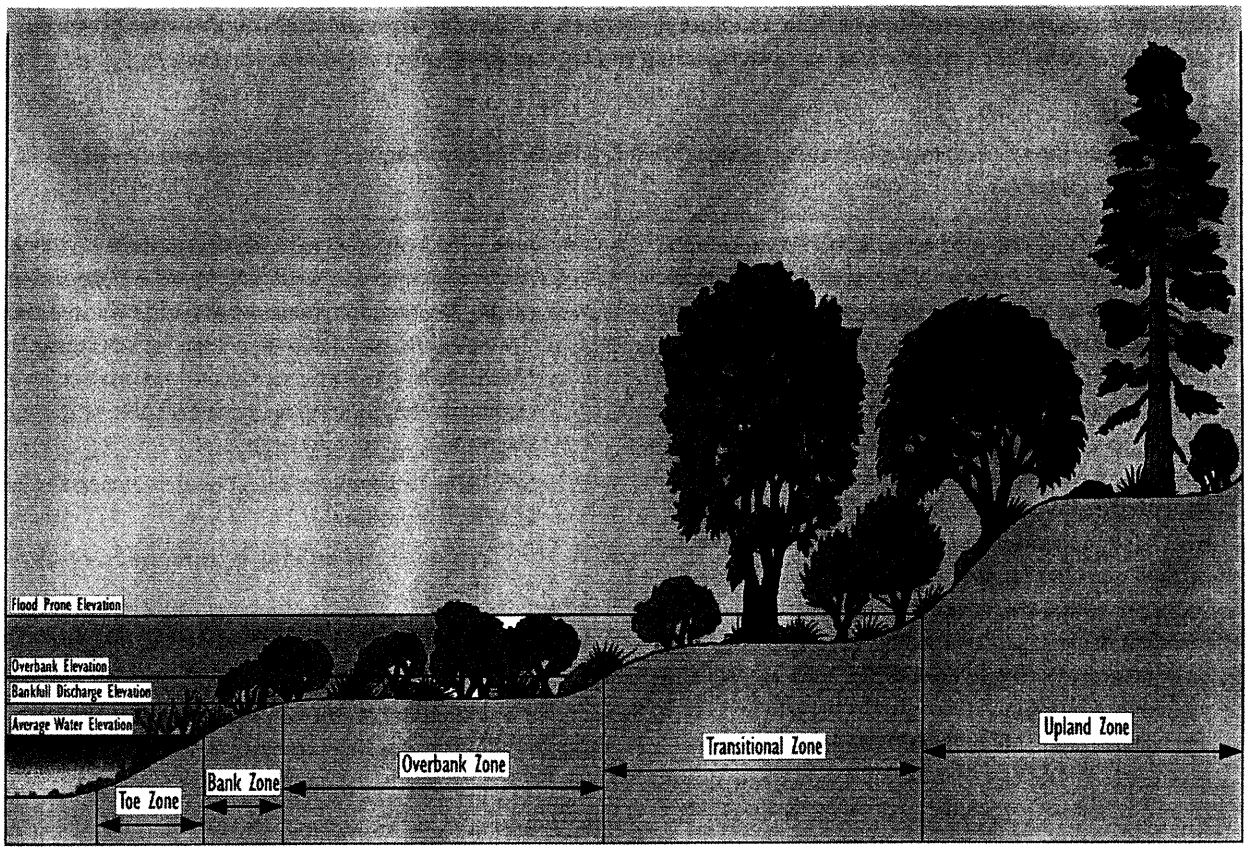


Figure 1. Riparian planting zones are based on elevations associated with different water levels and velocities. Specific types of riparian vegetation correspond with each zone.

are often located in this zone, as well as larger shrub species of willows and other riparian species.

The upland zone is area above the flood-prone zone. Rarely does water ever get this high except in something like a 100-year flood event. Plants are not adapted to prolonged inundation and need to be drought tolerant rather than flood tolerant.

Types of Revegetation Treatments

Streambank bioengineering is a treatment used to reestablish woody and herbaceous plant species, stabilize streambanks, and to reestablish or improve riparian buffer zones. The stabilization of streambanks to reduce the amount of total suspended solids entering the riparian zones is receiving new accentuation. The principle behind streambank bioengineering is to use woody and herbaceous roots to increase the strength and structure of the soil (Schiechtl and Stern 1994, Biedenharn and others 1997, Bentrup and Hoag 1998, Grey and Leiser 1982, Grey and Sotir 1996).

There are a wide variety of different treatments used in streambank erosion control. Most of them use dormant nonrooted hardwood cuttings of willow, cottonwood, and red-osier dogwood. For example:

A willow wattle (also called a willow bundle or willow fascine) is a cigar shaped bundle of live nonrooted hardwood cuttings tied together and placed in a shallow trench in the toe zone (Figure 2A). It will provide protection from undercutting when placed correctly at the toe of the slope. If placed in the correct hydrologic zone, the willows will sprout and root. A wattle can also be used to break up slope length and decrease erosion caused by overland flow, high rainfall, or spring thawing of ground frost. The wattle diameter ranges from 3 to 24 in. (7.6 to 61 cm) and is dependent upon objective and application. Dogwood can also be used for wattles. The amount of nonrooted hardwood cuttings that are needed to build a wattle is dependent upon the diameter of the bundle and length of streambank being treated.

A brush mattress or brush matting (Figure 2B) uses a 4 to 6 inch (10 to 15 cm) thick mat of nonrooted willow cuttings anchored to an eroding streambank. The cut ends of the willows are placed in a trench at the toe of the slope and are anchored by a willow wattle that also protects the toe from undercutting. The willows will sprout and take root thus stabilizing the streambank with a dense matrix of roots. The sprouts will provide a buffer to move the velocity of the river away from the bank. A brush mattress is used to mainly protect the bank and overbank zones. It will also protect the toe zone when used in conjunction with a willow wattle. A brush mattress will also provide fish habitat, shade, and water quality improvements. The woody plants will provide as much protection to the bank as large angular rock rip-rap after they are established (Schiechtl and Stern 1994). A 10 ft (3 m) section of brush mattress takes about one full size pickup bed of willow cuttings (Bentrup and Hoag 1998).

A vertical bundle is similar to a willow wattle except that the bundles are placed in shallow trenches vertically up the slope (Figure 2C). Typically it will protect the toe, bank and overbank zones. Vertical bundles are used in places where the streams are "flashy" (they have high fluctuations in water level) and to establish willows under or through rock rip-rap. When placed vertically up the bank, the cuttings will root into the bank and send sprouts up out of the bank or up through the rock. When placed through rock, the willows will root in the bank under the rip-rap and sprout out over the water. This will provide more rapid shade over the water, better wildlife and fish habitat, and water quality improvements. Dogwood can also be used in this treatment. Vertical bundle diameters should be from 3 to 18 in. (7.6 to 45.7 cm) depending upon the application. The bundle height should be tall enough to extend from about 8 in. (20.3 cm) into the streambed to about 1 foot (0.3 m) above the top of the bank.

Pole plantings (Figure 2D) utilize dormant nonrooted hardwood cuttings that are large diameter branches with all the side branches and the top 2 feet of the stem removed. Most other applications leave the branches and tops on. The cuttings are placed in the ground deep enough to reach the lowest water table of the year and high enough to expose at least 1 to 2 buds. Root primordia will sprout roots when good soil to stem contact is made and exposed sections of the cutting will sprout stems and leaves. Benefits of the pole planting are stability where the plantings are exposed to high stream velocities, the ability to plant in areas where the water table is deeper than

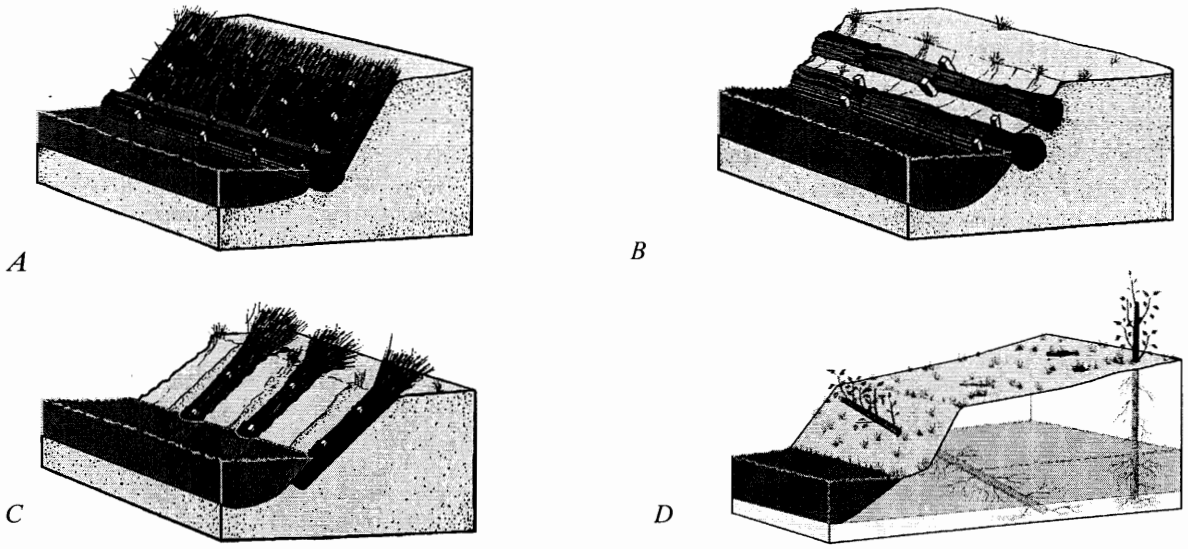


Figure 2A-D. Streambank bioengineering uses nonrooted hardwood cuttings of cottonwood and willows in a variety of treatments: A) brush mattress, B) willow wattle, C) vertical bundle, and D) pole cuttings.

one foot below the surface, and cost where pole plantings are significantly cheaper than bareroot or container stock (Bentrup and Hoag 1998, Carlson 1992, Hoag 1992, Hoag 1993a, and others).

Types of Plant Materials used in Stream Revegetation

There are two different categories of plant materials used in riparian revegetation: 1) dormant, nonrooted hardwood cuttings used in bioengineering applications and 2) live plants used for a variety of other purposes. Although many people think that large plants can be used for bioengineering, even the largest nursery stock cannot withstand the erosive action of water for the first few years. However, when planted in combination with bioengineered structures, nursery plants can promote streambank stability after their root systems become well established.

Dormant Nonrooted Hardwood Cuttings

The plant materials that are most widely-used in bioengineering treatments are dormant nonrooted hardwood cuttings that are used in bundles, fascines, and other bioengineering structures (Figure 2A-D). Cuttings are preferred because of their availability, ease of harvest, ease of planting, and their ability to root. Willow, cottonwood, and red-osier dogwood are the most common species used because of their ease of rooting and planting as well as tolerance to saturated soils and even periodic inundation. Few other riparian woody plants easily root from hardwood cuttings and so must be propagated by seed. A list of suitable species for streambank bioengineering is provided in the National Engineering Manual, Chapter 16, and the USDA NRCS Aberdeen Plant Materials Center Technical Note 32, and others. Both of these publications can be obtained from your local NRCS field office.

Woody stems or large branches should be collected from donor plants near the project area during the winter dormant season. Collections should be made from as many different plants as possible to promote biodiversity. After collection, the cuttings can either be stored for future planting or transported to the planting site. At the planting site they are soaked in water for 1 to 7 days prior to use (Hoag 1993b).

For revegetation projects that will require a large amount of plant material over several years, cuttings from **donor** plants can be brought back to a nursery for multiplication. This is particularly useful for remote projects, such as high elevations, where field collections would be difficult. **Mother** plants are established in nurseries to provide a source of cuttings. Stooling beds are hedge-like

rows of mother plants that are established in bareroot nurseries. Single mother plants can also be established in large containers. Besides the convenience, cuttings collected at the nursery often perform better than wild collections. For example, over 90% of narrowleaf cottonwood (*Populus angustifolia*) cuttings collected from stooling beds rooted whereas wild cuttings had only 62 to 85% rooting success (Dreesen and Harrington 1999).

Three size classes of cuttings are used in riparian bioengineering structures: propagation cuttings, branched cuttings, and poles (Table 1).

Propagation cuttings—These cuttings are relatively small (Table 1) and are used only in nursery propagation. Dormant hardwood cuttings are most commonly used although softwood cuttings from tips of actively growing plants are necessary to propagate some species (Dumroese and others 1997). Although propagation cuttings can be collected from donor plants near the project site, it is more efficient to establish stooling beds or mother plants at a nursery. Another option is serial propagation where cuttings can be harvested from the current year's crop.

Stem cuttings have an inherent polarity and will always produce shoots at the distal end (nearest the bud) and roots at the proximal end (nearest the main stem or root system). To distinguish between the top and bottom of hardwood cuttings, the bottoms are cut at an angle, which not only ensures that the cuttings are planted right side up but makes them easier to stick into containers or nursery beds (Hartmann and others 1997). In nursery stooling beds, willow and poplar are collected as long cuttings or whips that are then cut into the proper length. If collected by hand, the basal cut is typically made just below a node where roots form more readily. When large numbers of cuttings have to be made, then bundles of whips are cut with a band saw. Bundles of cuttings are then secured with a rubber band and stored under refrigeration at 32 to 40 °F (0 to 4.5 °C) to keep them dormant until they are planted (Landis and others 1999). Cultural procedures for growing propagation cuttings in either bareroot beds or containers are discussed in the Nursery Plants section.

Branched cuttings—This class includes branches and stems that are relatively large (Table 1). Branched cuttings can be collected near the project site or from stooling beds in a nursery. If the project area is far from the nursery, the large volume of plant material needed may make it more practical to collect on-site. Branched cuttings often have the tops and flowering parts cut off before they can be used for some of the bioengineering treatments. They differ from propagation cuttings and poles in that side branches are left in place during processing (Carlson and others 1992, Bentrup and Hoag 1998).

Branched cuttings are very effective for streambank erosion control when collectively used in brush mattresses, fascines, and vertical bundles (Figure 2A-C). Branched cuttings can be collected from native cottonwood or willow stands, and limited harvesting does not permanently harm the stands because these species readily resprout. In fact, harvesting can actually help to rejuvenate decadent stands. Up to 20% deadwood can be included with branched cuttings in bioengineering applications. The deadwood provides structural rigidity to the bioengineering treatments. Although branched cuttings typically have lower establishment rates than propagation cuttings, bioengineering structures made with branched cuttings are essential to initial stream stabilization.

Poles—Many riparian revegetation projects fail because high water velocities rip the plants out before they have a chance to establish an extensive root system, or they die when soils dry out later in the summer and fall. Pole plantings provide a means to overcome both of these problems (Table 1). The basic idea is to plant long cuttings of dormant willow and cottonwood (Figure 2D) to a sufficient depth that they will stay in the water table throughout the year. These species have dormant root primordia underneath their bark so that roots will sprout along the entire buried section and the poles will establish quickly after outplanting. The other benefit is that these large diameter pole cuttings will remain anchored during floods (Hoag 1993b).

Because of the large size of the plant material, mother plants can be established in the nursery to produce poles. Carlson (1992) concluded that establishing and managing "orchards" for producing poles should be a top priority for forest and conservation nurseries. Much of the research in this area has been done in the Southwestern

US. At the Los Lunas Plant Materials Center in New Mexico, pole cuttings are grown in production blocks that yield large poles after 3 growing seasons (Dreesen and Harrington 1999). Another possibility that is being tried at the J. Herbert Stone Nursery in Oregon is to convert existing willow stooling beds over to pole production.

As with other types of woody, nonrooted hardwood cuttings, poles are harvested during the winter dormant season with loppers, handsaws, brush cutters (with smaller diameter species), and chain saws. A large number can be harvested in a relatively short time with an experienced well-trained crew and transported to the planting site. Poles are prepared by removing the side branches and tops, packing them into bundles, and then shipping them to the customer. Prior to planting, post cuttings are soaked for 1 to 7 days to allow the root primordia to swell to the point they are ready to emerge from the bark. Once the roots emerge, it is much harder to plant the cutting because the roots are so tender that they are easily scraped off when planting them.

Poles can be planted in holes slightly larger than their diameter. This significantly increases the potential number of planting methods that can be used. Chainsaw augers, bucket augers, dibble bars, planting bars, and a tractor-mounted piece of equipment called the Stinger have all been used to plant poles (Hoag 1993c). Poles that fail to grow can be easily replaced by pulling them out of the hole and shoving a replacement back into the same hole with minimal effort.

Nursery Plants

Container or bareroot plants add diversity to the riparian revegetation area by ensuring the establishment of species that do not root readily from woody cuttings. Many people just assume that all willows or cottonwoods will root easily and so stick hardwood cuttings directly into the streambank. Although many of these cuttings will sprout shoots initially, some will tend to dieback later in the season due to poor root egress or pathogenic cankers.

Propagation method—The choice of propagation method is important and both the biology of the species and the objectives of the revegetation project must be considered. Many keystone riparian trees and shrubs including cottonwood and willow can be produced vegetatively, but some species or ecotypes are recalcitrant. For example, standard hardwood cuttings of Scouler willow do not root well, even in the nursery, and so this species must be propagated by other means (Dumroese and others 1997).

If it is possible to propagate a plant either by seed or vegetatively, then the amount of genetic variability that is desired in the crop must be considered. Sexual reproduction results in a mixture of genetic characteristics in the offspring, so each plant will appear slightly different from its parents and each other (Figure 3). Because maintenance of genetic diversity is so important in ecosystem management, seed propagation is encouraged whenever possible because it is easier to capture and preserve biodiversity with seeds

Table 1. Types of cuttings used in riparian revegetation.

Type of Cutting	Diameter	Length	Type of Wood	Pre-Rooted	Use
Propagation	0.2 to 0.8 in. (0.5 to 2 cm)	4 to 10 in. (10 to 25 cm)	Softwood or Hardwood	Yes	Live plants: Grown in bareroot beds or containers at nurseries
Branched	0.5 to 2 in. (1.3 to 5.1 cm)	4 to 15 feet (1.2 to 4.6 m)	Hardwood	No	Bioengineering: brush mattresses, fascines, vertical bundles at the project site
Pole	0.75 to 8 in. (1.9 to 20.3 cm)	3 to 12 feet (0.9 to 3.6 m)	Hardwood	No	Bioengineering: individual placement at the project site

than with vegetative propagation. When harvesting seeds or cuttings, collections should be made from as many individual plants as possible to maximize genetic diversity. Guinon (1993) provides an excellent discussion of all the factors involved in preserving biodiversity when collecting seeds or cuttings, and suggests a general guideline of 50 to 100 donor plants.

Nursery plants are traditionally divided into 2 major stock types: container and bareroot.

Bareroot stock—Bareroot nursery stock is grown in soil either from direct sowing, transplanting smaller bareroot or container plants, or rooting propagation cuttings. Because of the higher cost of establishment and longer production times, bareroot seedlings are less commonly used for riparian revegetation. However, bareroot plants are usually less expensive to produce, handle and transport than large container stock.

Seedlings—Few riparian plants are grown as bareroot seedlings because often the seeds are

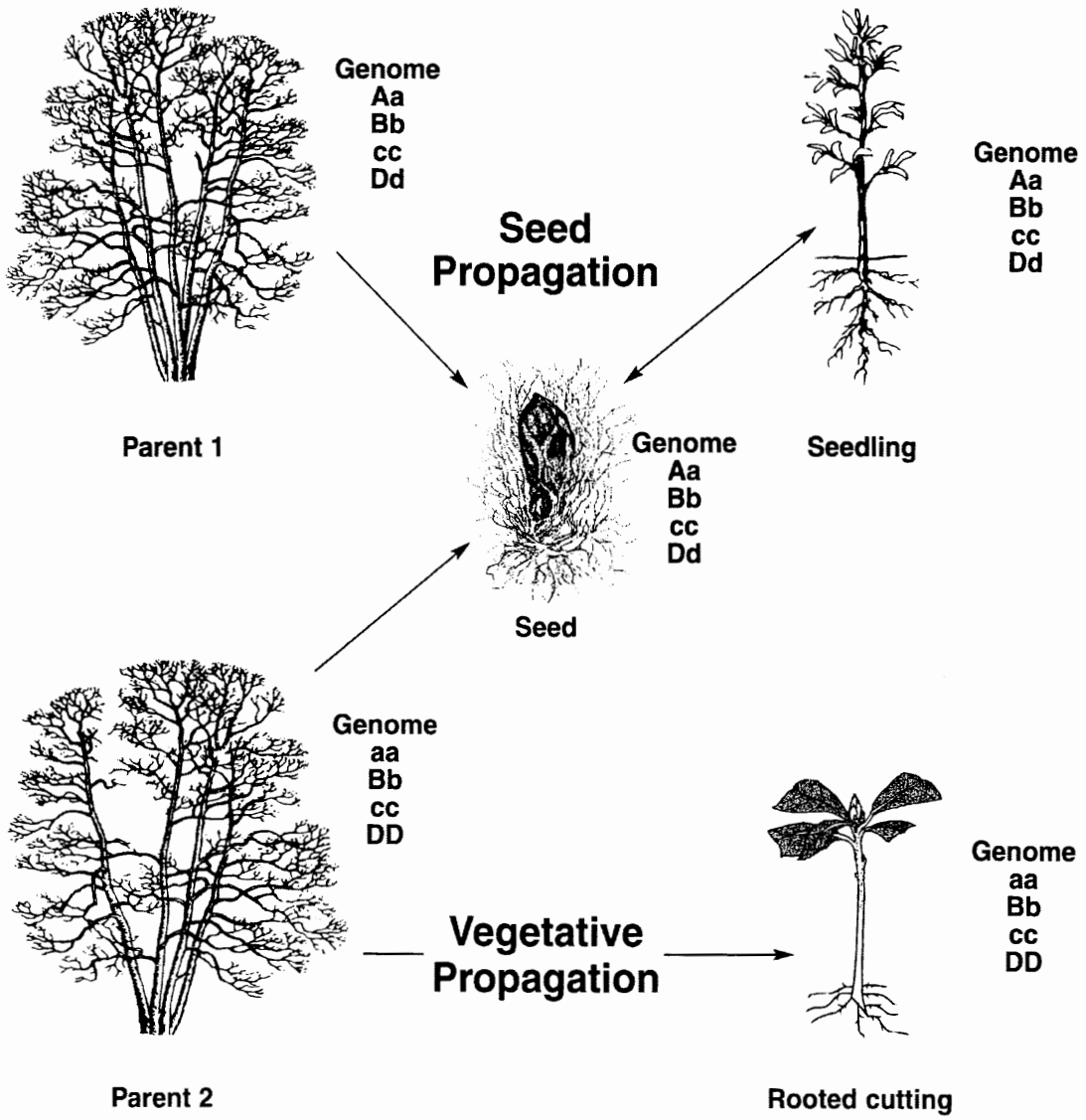


Figure 3. Plants propagated from seed look different from their parents and each other because they contain a mixture of the genetic characteristics of the 2-parent plants. Vegetative propagation, on the other hand, produces exact duplicates of the parents.

difficult to handle or they have complicated dormancy. For example, cottonwoods and willows have very small seeds that are short lived and they are covered with fine hairs that resist water imbibition making them difficult to propagate in bareroot seedbeds. Some nurseries do produce bareroot seedlings of riparian trees such as ash and oaks, and other species could be grown if the markets existed.

Rooted cuttings—Several riparian species are routinely propagated from short hardwood cuttings, especially cottonwoods and willows. Because they root easily and require less cultural attention than seedlings, rooted cuttings of these species grow rapidly and shippable plants can easily be produced in 1 season. In southern California, large black willow (*S. goodingii*) plants (> 6 ft or 1.8 m) are produced from hardwood cuttings in 1 year (Evans 1992). Planting and cultural techniques for propagating poplars and willows are provided by Morgenson (1992).

Bareroot transplants—Transplants are seedlings that have been harvested from their seedbeds or containers and then replanted in another location for additional growth. Traditionally, most transplants were bareroot seedlings grown for 1 or 2 years, replanted into a transplant bed, and then allowed to grow for another year or two. Transplanting small container seedlings into a bareroot nursery for an additional year or two of growth produces this stock type, also called a plug transplant. "Plug+1s" are an economical way to grow large stock types for riparian revegetation projects. In the last few years, container-to-container transplants are becoming more popular.

Container stock—Container plants can be produced by sowing seed or sticking propagation cuttings into containers and then growing them for 6 months to 1 year in a greenhouse or open compound. Container plants are preferred for riparian revegetation projects because they are quick to produce, easy to handle, and often have better outplanting performance on tough sites than bareroot stock. For riparian projects, container stock can be divided into 2 categories: small and large. We usually recommend as large a plant as possible because, other things being equal, large plants have more expansive and aggressive roots systems and can better withstand water erosion. Smaller container plants also cannot handle the water fluctuations as well as the larger sized stock. Of course, other considerations such as cost per plant and handling on the outplanting site will also affect the choice of stock type.

Small Containers ("Plugs")—Woody shrubs, grasses and wetland plants are often grown in small containers (volumes less than 15 in^3 or 245 cm^3). Plugs are used in bioengineering designs when the water is too deep or persistent to get woody plants established in other ways. For example, plugs are preferred over direct seeding because seeds of many herbaceous riparian plants need 3 things to germinate: water, heat, and light. The light requirement means that seeds must be sown on the surface and, as soon as water is released back into the site, the seeds float. Once this happens, the wind will concentrate them at the shoreline and prevent good plant distribution. Because of the light and heat germination requirement, few riparian herbaceous plant seeds will germinate in deep standing water. Transplanting wild plants ("wildlings") is sometimes used but small volume containers have been shown to have higher establishment rates and to spread faster and further (Hoag 1994).

Riparian herbaceous plant plugs also promote the trapping of sediments that will rebuild the streambank and will also increase the natural establishment of woody plant species. The fine root hairs of grasses or wetland plants, when combined with the larger deeper roots of woody plants, help bind the soil particles together and reduce streambank erosion. Sedges (*Carex* sp.), spikerush (*Eleocharis* sp.), bulrush (*Scirpus* sp.) and rushes (*Juncus* sp.) are used extensively in riparian and wetland revegetation because of their aggressive root systems. Manning and Padgett (1989) demonstrated that Nebraska sedge (*Carex nebrascensis*) had 112 feet of roots per cubic foot of soil (1205 m/m^3) in the top 4 in. (10.2 cm) of the soil profile. They also found that its root system extended as much as 6 feet (1.8 m) deep in some areas, which is significantly better than typical grass species found in the same area.

Large containers—We define large containers as ranging in volume from 15 in^3 (245 cm^3) to 5 gallons (18.9 l). Large stock types are becoming more popular in riparian revegetation because they handle the changing water table and erosive effects of floods better than smaller plants. Large container plants are used extensively in the overbank and transitional zones (Figure 1) to

produce immediate shade on the water, and allow sedimentation on the floodplain. Large plants have faster growth rates and, when they die and fall over, they provide large woody debris in the stream to create fish habitat. This is particularly critical for salmon revegetation efforts where many plant species have been eliminated by logging or grazing. In the Pacific Northwest, species grown for the overbank and transitional zones include conifer evergreens like spruce, hemlock, western redcedar, and other broadleaf trees like ash, hackberry, and some of the tree-type willows that can not be planted in the channel itself. In addition to improving the physical structure of the riparian zone, large container stock increases biodiversity and provides quick food and habitat for a wide variety of wildlife. For example, large stock types were used to produce "instant habitat" for the Least Bells' Vireo (*Vireo bellii*), an endangered bird in a Southern California riparian community (Evans 1992).

Propagation protocols—The propagation of riparian plants is a relatively new phenomenon and so reliable information on how to germinate seeds or root cuttings is often hard to find. For this reason, the U.S. Forest Service has started collecting comprehensive "recipes" on how to propagate native plants. A typical protocol starts with target seedling specifications and then discusses seed and/or vegetative propagation information, ending with the season of outplanting. Protocols should also include a crop production schedule that gives a visual calendar of the propagation process (Landis and others 1999). Propagation protocols for a wide variety of native plants are being developed and uploaded in the Native Plant Network:
http://www.nativeplantnetwork.org

Other propagation information is also available. The Nursery Technology Cooperative at Oregon State University recently published Propagation of Pacific Northwest Native Plants (Rose and others 1998), which contains information on riparian trees, shrubs, and other plants. The National Proceedings of the Forest and Conservation Nursery Associations are a good source of propagation information (for example, Dumroese and others 1997) as is the Combined Proceedings of the International Plant Propagation Society.

New nursery managers, in particular, are going to need some basic cultural information before starting to plan for a potential crop. The indirect experience gained by talking to other growers, although time-consuming, is valuable. Many private nurseries do not want to share their propagation secrets for obvious reasons, but government nurseries are excellent sources of technical information, as most consider technology transfer to be part of their mandate. The J. Herbert Stone nursery of the USDA-Forest Service has propagation information on bareroot cuttings of willows and cottonwoods and small and large container riparian plants.

The USDA-NRCS Plant Materials Centers are also a good source of information. For example, the Interagency Riparian/Wetland Plant Development Project at the in Aberdeen, ID PMC has documented efficient seed germination protocols for 6 different species of wetland plants. These protocols have increased the efficiency and reduced the cost of propagating riparian plants (Hoag 1994; Hoag and Sellers 1994).

Impacts on Nurseries

Even though streambank bioengineering is relatively new in this country and has not been totally accepted by the engineering profession, it is gaining in popularity and reputation. Many regulatory agencies are requiring plants be part of any structural work that is done in the riparian zone. Much research has been done on ways to improve on establishment techniques for woody plants in conjunction with rock structures. In many cases, it has been demonstrated that the vegetation can improve the rock structure, reduce the maintenance requirements, increase the long-term strength, and provide benefits like aesthetics, wildlife habitat, and water quality improvements.

The nursery trade must understand that streambank projects are requiring different types of plant material stock than what they have been used to providing. There is a large market developing for dormant nonrooted hardwood cuttings of willows, cottonwoods, and dogwoods that are large diameter, vigorous, healthy, and relatively free of insect and disease damage. Mother plants that are planted in a controlled environment such as a nursery can provide an easy and economical source of cuttings for many years. The idea that cuttings can be grown, cut, bundled and delivered to the planting site is becoming more widespread. Both large and small container

stock of native woody and herbaceous plants are needed in large numbers not only for riparian revegetation projects, but also for constructed wetland systems that are being used to cleanup agricultural wastewater.

Nurseries will need lead time to begin growing these native ecotype stock types. In many cases, the nurseries are able to contract the actual collection of seeds and cuttings from a revegetation site, take the seeds and cuttings back to the nursery, grow the plants according to the exact specifications of the buyer, and delivery the plants to the planting site. Some nurseries are contracting to plant the plants after they have grown them.

Although cost has been a major restriction in the past, the Endangered Species Act and other legislation will require the use of native ecotypes in a variety of stock sizes. The timing of this new market is being pushed rapidly to the forefront of many agencies' priorities and the nursery trade must respond or it will be left behind. Nurseries must expand out of their traditional markets and into the realm of seed and cutting collection, custom propagation, and planting.

Conclusions and Recommendations

1. Pursue new markets. Time is critical as markets for native riparian plant material are developing rapidly. Therefore, nurseries must be aggressive and seek out new customers to introduce their products and services. Attend meetings of potential customers and use new marketing techniques like establishing a website on the internet.
2. Practice "Show and Tell." Many customers have no understanding of nursery procedures or potential so be sure to show potential customers what you can produce—both species and stock types. Invite potential customers to an open house at your nursery to show what types of plant materials you can produce. Showing is always better than telling, so try to grow some typical riparian plants or establish stooling beds or mother plants ahead of time.
3. Emphasize "source-identified" and "locally-adapted." Many project managers, especially engineers and even other biologists, do not understand that revegetation projects have different objectives than other types of plantings. Explain the importance of using native plant material that is collected at their project area and adapted to the local environment. When growing sample plants, make sure that you have the proper sources for a specific project.

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THE IR-4 PROGRAM— HOW IT CAN BENEFIT NURSERIES

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Key Words

Pesticides, pesticide label, pesticide registration

The Interregional Research Project 4 (IR-4) was initiated in 1963 to obtain national pesticide label registrations for use on food and fiber. This program has an emphasis on minor uses or specialty crops. In this arena in the United States today it includes 600 crops.

This national program includes the U.S. Department of Agriculture, Agricultural Research Service (USDA/ARS), and the U.S. Department of Agriculture Cooperative State Research Education and Extension Service (USDA/CSREES) as the major funding organizations. IR-4 also has a cooperative partnership with the Environmental Protection Agency (US EPA), the State Agricultural Experiment Stations (SAES), agricultural chemical companies, commodity organizations, and individual growers.

The IR-4 program, which was expanded in 1977 to include ornamentals research for nursery and floral crops for label expansion, now includes floral, forestry, nursery, turf, and Christmas tree production. Research is also conducted to develop data for pesticide registrations for commercial landscape, interior plantscape, and tissue culture. Since 1982, national registration was initiated to include biological pest control agents such as microbials and biopesticides.

The IR-4 national headquarters staff is based as part of the New Jersey Agricultural Experiment Station (NJAES) at Rutgers University. It provides the leadership and coordination for this diverse program.

The IR-4 is divided into 4 regions, each led by a regional coordinator. Each state has a representative to provide input for future research needs. A companion minor use program is administered by USDA/ARS. The USDA/ARS minor use program operates in concert with the IR-4 in the clearance of minor uses.

Since the IR-4 ornamental pesticide program was initiated in 1977, we have had requests for over 18,000 researchable projects.

Table 1. IR-4 Ornamental Research 1977-1998

	Total Researchable Projects	Total Registrants
Fungicides	5954	1979
Herbicides	5326	1600
Insecticides	6659	1800
Molluscicides	99	4
Nematicides	350	80
PGRs	224	64
Rodenticides	4	3
Total	**18,616**	**5,530**

IR-4 ornamental research during this same period (1997 to 1998) developed data that led to over 5,500 national label registrations (Table 1). During the last 3 years (1996 through 1998) we conducted 1,444 research trials for an average of 481 per year (Table 2). During this same period 1,539 new registrations were obtained (Table 2). This includes 513 new registrations in 1998.

Table 2. IR-4 Ornamental Research

	1996	1997	1998
Research Trials	445	539	460
New Registrants	891	135	513

Appendix 1

During 1998, data were collected for these 13 fungicides, 20 herbicides, and 15 insecticides.

FUNGICIDES	HERBICIDES	INSECTICIDES
Ampelomyces quisqualis (AQ-10 Biofungicide)	Atrazine (Atrex)	Acephate (Orthene/Turf, Tree and Ornamental Spray)
Bordeaux Mixture (13.3%)	Clethodim (Envoy 12.6%)	Carbofuran (Furadan)
Captan (Captan 50W)	2,4-D Amine (Amine 4)	Clofentazine(Ovation)
Chlorothalonil (Daconil Ultrex 82.5%)	2,4-D LV Ester (Weedone LV-4)	Permithrin (Astro)
Etridazole (Ethazole)	Dicamba (Vanquish)	Chlorpyrifos (Dursban 50W)
Flutolanil (Prostar 50 WP)	Dithiopyr (Dimension 1EC)	Diazinon (Knox Out 2FM)
Fosetyl-Al (Chipco Aliette WDG 80)	Diuron (Direx 80 DF)	Diflubenzuron (Dimilin)
Mefenoxam + Mancozeb (Ridomil-Gold MZ)	Fluazifop-butyl (Fusilade)	Dimethoate (Cygon)
Oxytetracycline (Mycoshield)	Halosulfuron Methyl (Permit)	Fenitrothion (Pestroy 4EC)
Physan 20	Isoxaben (Gallery 75DF)	Fipronil (Chipco Choice)
Streptomycin (Agrimycin 17)	Napropamide (Devrinol 5G, 50 DF)	Formetanate Hydrochloride (Carzol SP)
Tebuconazole (Lynx 25)	Oryzalin (Surflan 40.4%, XL, 2G)	Pirimicarb (Pirimor 50 DF)
Thiophanate Methyl (Clearys 3336 4.5F)	Oxadiazon (Chipco Ronstar G, 50WP)	Pyridaben (Sanmite 75 DF)
	Oxyfluorfen (Goal T/O 2XL)	Tefluthrin (Fireban 1.5G)
	Pendimethalin (Pendulum (60 WG)	Trichlorfon (Dylox 80)
	Pendimethalin G (Ornamental Weed Grass)	
	Prodiamine (Barricade 65 WG, Factor 65)	
	Trifluralin (Trifluralin 10G)	

Appendix 2

1998 pesticide registrations supported by IR-4 Data

FUNGICIDES

Chlorothalonil (Bravo, Daconil)
- African Violet
- Ageratum
- Fir (Abies)
- Fuchsia
- Gloxinia
- Larkspur
- Nasturtium
- Periwinkle (Vinca)
- Persian Violet (Cyclamen)
- Pinks (Dianthus)
- Primrose
- Snapdragon
- Vervain (Verbena)

Chlorothalonil (Exotherm)
- Poinsettia

Copper hydroxide (Kocide)
- Aglaonema
- Elm
- Flag
- Honey Locust
- Honeysuckle
- Nephtytis
- Rose-of-Sharon
- Snapdragon
- Umbrella Tree

Etridazole (Ethazole)
- Marigold
- Petunia
- Scarlet Sage
- Shrub Verbena (Lantana)

Flutolanil (Prostar)
- Azalea
- Balsam
- Begonia

Fosetyl-al (Chipco Aliette)
- Arrowwood (Viburnum)

Gliocladium virens (Soil Gard)
- Balsam (Impatiens)
- Begonia
- Cockscomb
- Marigold
- Petunia
- Scarlet Sage
- Snapdragon
- Zinnia

Mancozeb (Penncozeb, Protect T/O)
- Frangipani (Plumeria)
- Gloxinia
- Hackberry

Mefenoxam (Subdue Maxx)
- Bleeding heart
- Snapdragon
- StoneCrop

Oxythioquinox (Morestan)
- Japanese Spurge (Pachysandra)

Thiophanate methyl (Clearys 3336)
- Agertum
- Babysbreath
- Begonias
- Blanket Flower
- Bougainevillea
- Carnation
- Chrysanthemum
- Coleus
- Coneflower
- Crossandra
- Fuschia
- Gazania
- Geranium
- Globe amaranth
- Hibiscus
- Impatiens
- Larkspur
- Marigold
- Moss Rose
- Nicotiana
- Ornamental Cabbage
- Ornamental Kale
- Petunia
- Phlox
- Austrian Pine
- Pinks
- Pocketbook Flower
- Primrose
- Rose Periwinkle (Catharanthus)
- Scarlet Sage
- Shasta Daisy
- Snapdragon
- Statice
- Stock
- Tickseed
- Transvaal Daisy
- Vervain (Verbena)
- Violet

Vinclozolin (Ornalin)
- Hydrangea

HERBICIDES

Bentazon (Basagran)
- Crabapple (non-bearing)
- Holly
- Marigold
- Oak
- Petunia
- Yew (Taxus)

Clethodim (Select)
- Ageratum
- Snapdragon

Clopyralid (Lontrel)
- Arborvitae
- Azalea
- Bridal-Wreath
- Christmas Trees
- Crabapple (non-bearing)
- Douglas-fir (Pseudotsuga)
- Fir (Abies)
- Flowering Dogwood
- Juniper
- Maple
- Oak
- Pine
- Mugo Pine
- Rhododendron
- Spruce
- Norway Spruce
- White Spruce
- Yew (Taxus)

Dithiopyr (Dimension)
- Arrowwood (Viburnum)
- Tree Fern (Asparagus)
- Geranium
- Hawthorn
- Juniper
- Lilac
- Sugar Maple
- Red Oak
- Yew (Taxus)

Diuron
- Ash

Isoxaben
- Arrowwood (viburnum
- River Birch
- Blue Fescue
- Chinese Pennisetum
- False Spirea (Astilbe)
- Heath
- Heather
- Blue Holly
- Japanese Flowering Cherry
- Southern Magnolia
- Redbud
- Wax Myrtle

Isoxaben + trifluralin (Snapshot 2.5 TG)
- Pygmy Date Palm (Phoenix)

Metolachlor (Pennant)
- Snapdragon

Metolachlor + simazine (Derby)
- Birch

Oryzalin (Surflan)
- Arrowwood (Viburnum)
- White Ash
- Bellflower
- River Birch
- Japanese Dogwood
- Redbud

Oxadiazon (Ronstar)
- Baby's Breath
- Bald Cypress
- Blanket Flower
- Blazing-Star
- Cheddar Pink
- Cleyera
- Dahlia
- Daylily
- Golden-Rain Tree
- Hardy Ice Plant
- Hardy Mum
- Lambs Ears
- Lance Coreopsis
- Leopards Bane
- Plantain Lily
- Linden
- Mock Orange
- Statice (Limonium)
- Peony
- Sweet William
- TickseedWhite Spruce

Oxyfluorfen + oryzalin (Rout)
- Honeysuckle (Lonicera)

Pendimethalin (Pendulum)
- Avens (Geum)
- Yarrow (Achillea)

Pronamide (Kerb)
- Maple
- Oak

Sethoxydim (Poast)
- English Ivy (Hedera)

Simazine (Princep)
- Flowering Dogwood
- Holly
- American Holly
- Blue Holly
- Fosters Holly
- Honey Locust
- Japanese Dogwood

Trifluralin (Treflan)
- Blue Fescue
- Cheddar Pink
- Rose
- Speedwell (Veronica)
- Stonecrop (Sedum)

INSECTICIDES

Acephate (Orthene)
- Arborvitae
- Aster

Balsam (Impatiens)
- Birch
- Chrysanthemum

Bendiocarb (Turcam, Dycarb)
- Holly (Ilex)

Carbofuran (Furadan)
- Azalea
- Rhododendron
- Yew (Taxus)

Cyfluthrin (Baythroid)
- Balsam (Impatiens)
- Calendula
- Carnation
- Chrysanthemum
- Geranium
- Poinsettia
- Primrose

Cyromazine (Citation)
- Calendula

Diazinon (Knox Out)
- Ageratum
- River Birch
- Blazing-Star (Liatris)
- Chrysanthemum
- Crabapple (non-bearing)
- Crape Myrtle
- Leyland Cypress
- Flowering Dogwood
- French Hydrangea
- Holly
- American Holly
- Blue Holly
- Fosters Holly
- Honey Locust
- Japanese Dogwood
- Japanese Flowering Cherry
- Foxglove
- Lobelia
- Saucer Magnolia
- Southern Magnolia
- Star Magnolia
- Amur Maple
- Paperbark Maple
- Red Maple
- Sugar Maple
- Trident Maple
- Bradford Pear
- Rose-of-Sharon
- Scarlet Sage
- Sweet Gum
- Tulip Tree
- Wax Myrtle
- Weeping Willow
- Western Magwort
- Yarrow (Achillea)

Prodiamine (Barricade)
- Andromeda
- Arborvitae
- Arrowwood (Viburnum)
- Aucuba
- Azalea
- Barberry
- Begonia
- Bellflower (Campanula)
- Bluespire (Perovskia)
- Boltonia
- Boxwood
- Bridal Wreath (Spirea)
- Butterfly Bush (Buddleia)
- Carpobrotus
- Chinese Pistachio
- Cleyera
- Gazania
- Japanese Spurge
- Scarlet Sage (Salvia)
- Velvet Plant
- Wax Vine (Hoya)

Isofenphos (Oftanol)
- Christmas Tree
- Japanese Holly

Permethrin (Astro)
- Ash
- Azalea
- Beech
- Birch
- Black Locust
- Cherry (non-bearing)
- Cottonwood
- Elm
- Eucalyptus
- Flowering Dogwood
- Freesia
- Hawthorn
- Hickory
- Honey Locust
- Hop Hornbeam
- Lilac
- Maple
- Mountain Ash
- Oak
- Peach (non-bearing)
- Loblolly Pine
- Pitch Pine
- Red Pine
- Scotch Pine
- Spruce Pine
- Virginia Pine
- White Pine
- Poinsettia
- Rhododendron
- Willow

Pyridaben (Sanmite)
- Holly
- Juniper
- Rose
- Winged Euonymus

Sunspray Ultra-Fine Spray Oil
- Agertum

PLANT GROWTH REGULATORS

Ancymidol (A-Rest)
- Angelonia
- Coleus
- Coral Plant
- Cotonester
- Crabapple (non-bearing)
- Crape Myrtle
- Cypress
- Daffodil
- Daylily
- Douglas-fir (Pseudotsuga)
- False Cypress
- False Dragon Head (Physotegia)
- Flowering Dogwood
- Forsythia
- French Hydrangea
- Gardenia
- Geranium
- Heavenly Bamboo (Nandina)
- Hemlock
- Hardy Ice Plant (Delosperma)
- American Holly
- Japanese Holly
- Honeysuckle
- Hopbush (Dodonaea)
- Japanese Flowering Cherry
- Japanese Pittosporum
- Juniper
- Larkspur
- Lily
- Plantain Lily (Hosta)
- Lilyturf (Liriope)
- Creeping Lilyturf
- Giant Lilyturf
- Lobelia
- Magnolia
- Saucer Magnolia
- Star Magnolia
- Maple
- Oak
- Oleander
- Pampas Grass
- Bradford Pear
- Peony
- Periwinkle (Vinca)
- Potentilla (Cinquefoil)
- Privet (Ligustrum)
- Purpleleaf-Wintercreeper
- Rhododendron
- Rose-of-Sharon
- Rodgersia
- Southern Yew

(Podocarpus)
- Spruce
- Star Jasmine
- Stone Crop (Sedum)
- Trailing Lantana
- Weigela
- Coral Porterweed
- Egyptian Star Cluster
- Mexican Petunia (Ruellia)
- Sweet Potato Vine
- Yellow Shrimp Plant

SOMETHING NEW—THE *NATIVE PLANTS JOURNAL*

R. KASTEN DUMROESE

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Abstract

The demand for native plants continues to increase, but published information on how to propagate natives is extremely limited. The *Native Plants Journal*, a full-color publication produced as a cooperative between the University of Idaho and the USDA Forest Service, provides a forum for sharing practical information about growing and planting native plants.

Key Words

Nursery, seedlings, Internet, plant production

Forest and conservation nurseries are being asked to propagate an increasingly wide variety of native plants, from ferns and forbs to shrubs and noncommercial trees. Learning how to propagate this variety of plants can be a formidable challenge. Recognizing this need, the Reforestation, Nurseries and Genetic Resources (RNGR) team of the USDA Forest Service came up with the idea of developing a publication for sharing information about growing and planting native plants: the *Native Plants Journal.* In spring 1999, a cooperative agreement was made between the University of Idaho Forest Research Nursery and the Forest Service to begin work on the first issue. The journal will be published twice each year in full color.

The journal, which I like to describe as an eclectic forum for dispersing practical information about planting and growing native plants, will be published in spring 2000. I serve as editor-in-chief. The aim of the journal is to publish a wide variety of information on a diverse number of species throughout North America. To ensure a continental coverage, the editorial board is composed of individuals across the US and Canada and reflects a range of specialties. Another objective of the journal is to provide opportunities for scientists to publish reviewed material (but still emphasizing practical importance) and for workers in the field to publish information they've discovered through experience. Therefore, the journal accepts 2 types of articles: refereed and general technical. Refereed articles undergo rigorous scientific review and are published with a notation indicating that. General technical articles, although also reviewed, are not held to the same rigorous scientific standards as refereed articles. General technical articles include things like propagation protocols, descriptions of equipment, case studies, new nursery techniques, and so on.

So, what will the first issue look like? Well, it will contain 13 articles. Refereed articles will discuss chilling requirements of eriogonums in Utah, establishing native grasses using herbicides in Kentucky, and a review article on the ecology, conservation, and propagation of an endangered goldenrod in Kentucky. General technical articles include fern propagation at Glacier National Park, prairie plant production in Illinois, propagation protocols for an endangered mallow in Illinois and wiregrass in Florida, using smoke to stimulate germination, nursery production of grass in Oregon, longleaf pine ecology and nursery production in the South, and instructions on how to make a dibble to plant hardwood cuttings.

The fall issue is shaping up as well. It will contain articles dealing with American Indians and how they propagate saguaro cactus, sweetgrass, and wild rice. We will also publish articles dealing with coir as a medium for growing Douglas-fir, harvesting native seeds with a hedge trimmer, oak miniplug production, and information on registering pesticides for specialty plants, among others.

All previously published articles will also be in a searchable database on the Internet (http://www.nativeplantnetwork.org). You may use either an author name or key words to search. Articles are available as PDFs for downloading to your computer or printing.

Currently, subscriptions are US $30 per year for individuals. Library rates are US $60 per year. Special subscriptions are available for students and multi-year subscriptions. For more information about subscribing, please contact the University of Idaho Press, PO Box 444416, Moscow, Idaho 83844-4416; telephone: 1.800.847.7377; fax: 1.208.885.3301; email: nativeplants@uidaho.edu.

Towner State Nursery Weed Control Program for Field-Grown Conifer Nursery Stock

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Key Words

Bareroot nursery, herbicides

The Towner State Nursery is owned and operated by the North Dakota Forest Service. The nursery is 160 acres in size and is located in north-central North Dakota. The Towner Nursery specializes in the production of conifer seedlings, transplants, and greenhouse-grown container stock for conservation tree plantings. Transplants constitute 80% of the stock produced. The Towner Nursery sells 33 size classes representing 17 tree species. Sales for 1999 totaled 1.4 million trees.

Goal® herbicide is the primary method of weed control at the Towner Nursery. Hand weeding is used to remove weeds that are not controlled by Goal®. Seedbed areas of the nursery are fumigated prior to sowing, but the primary purpose of fumigation is to control diseases, not weeds. Good weed control in seedbeds can be achieved with herbicides making fumigation unnecessary for weed control. Weeds are controlled in noncrop areas by cultivation and mowing.

Herbicide weed control

Seedbeds

One-half pound active ingredient per acre of Goal® 2 XL herbicide is applied immediately after sowing. A second application of Goal®, at 1 pound active ingredient per acre, is applied for second-season weed control in seedbeds.

Transplant fields

Trees are transplanted in both spring and fall at the Towner Nursery. Goal® 2 XL herbicide is applied after transplanting at a rate of 1 pound active ingredient per acre. A second application of Goal®, at the 1-pound rate, is applied at the beginning of the second season for continued weed control.

Irrigation

One-quarter inch of irrigation water is applied immediately following herbicide application.

Hand Weeding

- Hand weeding is used to control weeds that escape herbicide control. Crews collect weeds in pails while hand weeding to prevent weed seeds from germinating. Also, picking up weeds minimizes missed weeds by making them more visible.
- All fields are hand weeded 4 times per year.
- Mechanical cultivation of pathways between beds is used only if weeds are too numerous for hand weeding.

Weed Sanitation

- Grass areas are mowed to minimize production of weed seeds.
- Fallow areas are cultivated regularly to prevent weeds from producing seed.
- Noxious weeds and dandelions are controlled in windbreaks and grass areas by spraying with 2,4-D.

Costs to Keep Nursery Fields Free of Weeds

- Weed control adds 3 cents to the cost of producing a 2+2 transplant (almost 9% of the cost of a 35-cent tree).
- Herbicide application costs including product, equipment, and labor total about 1 cent per tree.
- Hand weeding costs add an additional 3/4 cents per tree (average labor cost of $6.00 per hour).
- Mowing and cultivation for weed control costs 3/4 cents per tree for equipment and labor.

Louisiana Department of Agriculture and Forestry Weed Control Program

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Key Words

Fumigation, bareroot nursery, herbicides

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1. Cover crops and nonproduction areas:

a. Herbicide application in cover crop areas
b. Cultivation prior to planting
c. Maintain clean turn rows
d. Brushhogging around and within nursery grounds to prevent seeding
e. Maintain good drainage to prevent backup over fields

2. Fumigation:

a. Use MC-2
b. Lift irrigation lines and fumigate entire field
c. Fumigate 10 feet beyond bed ends to prevent dragging untreated soil back into field
d. Add organic matter only to fields that are to be fumigated

3. Production areas:

a. Fumigate MC-2
b. Use pre-emergence herbicides over 95% of crop
c. Maintain weed-free riser rows, turn rows, and middles through herbicide applications and cultivation
d. Use 6 people working 20 hours per week from mid-May to June, goose picking beds
e. Drill spray seedling beds with Roundup® and Goal® with shielded applicator
f. Have recently tried Factor® 6 weeks after germination on some areas, not sure if we will continue use
g. Use Fusilaide® to control grasses

USE OF GEOGRAPHIC INFORMATION SYSTEM (GPS) IN NURSERIES

BRENT OLSON AND CHAD LORETH

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Key Words

Bareroot nursery, nursery cultural practices, research, Arcview

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The use of GIS in nursery operations provides a variety of opportunities.

- All planning activities can be incorporated into an accessible database.
- GIS can be used to create ways for employees to access and analyze data.
- The program can be used for historical record keeping.
- Use of GIS in planning can improve the efficiency of nursery operations.
- GIS can easily be used as a management tool.

Arcview 3.1 is the GIS system currently in use at the Ames Nursery. This program enables the user to accomplish multiple tasks which include:

- Heads up digitizing;
- Importing and creating database files
- Hot-linking to digital photos, text files, and a variety of other file types
- Importing GPS data, as well as data from CAD and DOQ
- Production of maps

Nursery management can benefit significantly from the use of GIS in a number of areas. At Ames, three areas of operations use GIS.

- Administration can use GIS for:
  - Cost accounting
  - Equipment inventory
  - Purchasing, including seed, equipment, chemicals, fertilizers, etc.
  - To assist in management planning
- Nursery research can use GIS for:
  - Tracking outplantings
  - Nursery history plots
  - Soil testing
  - Stock inventory
  - Irrigation
  - Permanent photo plots
- GIS can also be used to track cultural practices such as:
  - Irrigation
  - Chemical application
  - Fertilization
  - Undercutting and wrenching
  - Seeding
  - Top pruning

GIS coverage for Ames Nursery initially included a variety of information.

- Topographic maps (DRG)
- Ortho Quads (DOQ)
- NRCS Soils
- GSB information
- State-wide coverages

As the program has progressed, the nursery has developed (and is developing) site specific coverage, which includes:

- Nursery soils, including pH and sand, silt, clay, and loam content

- Irrigation tracking, including sprinkler systems, drains, valve locations, WDS, A/BGRD
- Building mapping and maintenance for administration, chemical storage, fertilizer storage
- Weather station information
- Road locations and maintenance
- Windbreaks, including shrubs, conifers, and hardwoods
- Past and present stock tracking
- Timber
- Property lines
- Seed collections sites.

In developing the planned use of GIS for other nurseries, the following is recommended:

- Identify uses of GIS for your program.
- Purchase PCs that are capable of running GIS.
- Research software packages for the PCs
- Develop lists of items to be digitized, and utilize existing data or coverages.
- Develop a task list and time line.

GLOBAL POSITIONING SYSTEM (GPS): CURRENT STATUS AND POSSIBLE NURSERY USES

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Key Words

MTDC, hardwood canopy, Douglas-fir canopy, precision agriculture

The GPS (Global Positioning System) is a worldwide satellite-positioning system that was funded, installed, and continues to be operated by the U.S. Department of Defense. The navigation signals are provided free and can be used by anyone who has the equipment necessary to receive them.

The Missoula Technology and Development Center (MTDC) became involved with GPS technology in August of 1983 when the Timber and Engineering Department, the program's main sponsors, recognized the potential of GPS for resource management activities. The USDA Forest Service's Washington Office assigned the project. Over the years, new sponsors have joined the program, which now includes the departments of Engineering, Timber Management, Fire and Aviation Management, Forest Health Protection, Recreation, Law Enforcement and Investigation, and Research, Lands, and Wildlife.

In October 1987 MTDC evaluated a GPS unit at a GPS test and training facility the MTDC had developed at the University of Montana's Lubrecht Experimental Forest. The performance of the GPS unit was impressive, especially for digitizing a road for mapping purposes. However, that evaluation pointed out a problem with the tree canopy attenuating the signal and reducing horizontal accuracy. A report was issued covering the overall evaluation of the unit.

Other test sites were established: 1 in the eastern hardwood forests of Indiana and 1 in a typical west coast Douglas-fir forest in Oregon. The additional sites allowed the Center to test GPS receivers under a variety of field conditions. The test site on the Hoosier National Forest near Bedford, IN, was established in April 1991. This site has a 7-point polygon under a mixed oak/hickory/beech canopy typical of old-growth central hardwoods. The west coast test site was set up in 1995 on the Clackamas District of the Mount Hood National Forest. The course consists of a 13-point polygon. It is under a heavy canopy of Douglas-fir and western hemlock overstory (24 to 40 inches in d.b.h.) with a vine maple and red alder understory. In 1998 a Northeastern test site was established at Ridley Creek State Park in Pennsylvania. It consists of a 12-point polygon under a poplar, oak, maple, and beech canopy.

Position control for all of these test sites was brought in with GPS. Conventional survey equipment was used to survey in the test sites under the canopy. The test sites allow us to evaluate GPS equipment under a variety of canopy conditions typical of those encountered by Forest Service users. Users can select the GPS receiver best suited for their job based on tests conducted in conditions similar to those they will encounter while working.

The GPS navigation signal has two parts: a Standard Positioning Service (SPS) using a Coarse Acquisition (C/A) or civilian code on the L1 frequency and a Precise Positioning Service (PPS) using the P(Y) code or military signal, available on the L1 and L2 frequencies. The PPS signal is only available to the military and authorized United States Government agencies. The C/A code is intentionally degraded. Its accuracy is only

guaranteed to be within 100 meters 95% of the time and within 300 meters 99% of the time. This intentional inaccuracy is called Selective Availability (SA). The PPS receivers have encryption devices that remove selective availability. These receivers provide autonomous accuracy on the order of 9 to 10 meters under the canopy.

A procedure known as differential correction was developed to improve the accuracy of the C/A signal and remove the selective availability. A second receiver is placed over a known point, or a base station is used and positions are recorded there while the roving second receiver is recording positions in the field. Because the base station receiver is on a known point, the difference between its recorded position and the known value is calculated. Position data from the roving receiver can be corrected using these values. Corrections can be made in real time if the correction signal is radioed back to the roving receiver. Otherwise, corrections can be made later by postprocessing the data.

In May 1994 the Forest Service Annex to the Memorandum of Agreement between the Department of Defense and the Department of Agriculture was signed. This agreement authorized the Forest Service and other agencies that signed annexes to use GPS receivers. Figure 1 shows some typical accuracies that can be obtained with PPS receivers and C/A code receivers.

New Opportunities in GPS

Satellite Broadcast of Differential Signal

In the past, local services (usually an FM radio station) had to be available to broadcast the differential correction signal to the remote GPS receiver. Another method was to set up a base station over a known point and relay that correction signal to the remote GPS receiver. Now a satellite service is available to relay the differential correction signal to GPS receivers that are equipped to receive them. The satellite providing this service is in a geosynchronous orbit near the equator. In the northern United States, this signal is hard to receive under a dense forest canopy.

Dual-Frequency Capability

If a receiver is capable of tracking both the L1 and L2 frequencies, it can compare these signals and reduce the amount of error caused by conditions in the ionosphere. This capability will be more common when new satellites become available with the second and third frequencies.

Second and Third Civil Frequencies

By 2005, two additional civil frequencies will be added to the replacement satellites for the GPS constellation. This system will be operational around the year 2010. There is some talk about moving the schedule up if Congress approves additional funding. With these additional frequencies a new military code will be added that will make the SA unnecessary. A vice-presidential order says that Selective Availability will be turned off by year 2006 if the military has an alternate method of ensuring national security. When Selective Availability is turned off, the position accuracy of standard handheld GPS receivers will be in the 8- to 10-meters range.

Differential GPS (DGPS) Continuous Coverage

The National Geodetic Survey is installing broadcast stations across the United States that will provide double-coverage broadcasting of the differential correctional signal anywhere in the United States. When the system is completed, receivers will be able to use differential correction for real-time accuracy in the order of 2 to 3 meters in the open and 5 to 8 meters under a forest canopy. The latest schedule for completion of these broadcast stations is the year 2003.

Embedded Chips

Electronic chips and boards with embedded GPS receivers are becoming commonplace. GPS will soon be widely used for navigation purposes in personal vehicles. Receivers are getting smaller (some are the size of a postage stamp), and they are becoming more sensitive.

New Techniques

Just as differential correction of the GPS signal has increased its accuracy, other techniques will be developed that will further increase accuracy and reduce the effects of multipath signals (those that bounce off objects such as cliffs). Techniques may

be developed for increasing the signal accuracy under the forest canopy.

Precision Agriculture

Precision agriculture uses GPS technology to record locations on agricultural fields and Geographic Information System, GIS, technology to store information about those locations to increase agricultural yields, precisely apply fertilizers and pesticides, and fine tune other agricultural practices. Precision agriculture allows farmers and ranchers to manage land by the square meter instead of the square mile.

The Components of Precision Agriculture

Observation—This takes place throughout the year. Tasks such as soil mapping, weed mapping, pest mapping, and recording crop growth, rainfall, and other unique conditions fall into this category. These observations need to be added to the database.

Analysis—The database of observed events needs to be put in a GIS. This information is updated periodically to keep the database current.

Timely and Precise Response to Fine-Scale Variation—With the use of variable rate technology, different parts of a field can receive different rates of spray or fertilizer. Matching the needs with the product is one of the benefits of precision agriculture.

Assessment—A harvest-yield monitor allows the field's productivity to be determined. Because the yield in different parts of the field is known, a manager can see if variable rate application produced the desired results. By reviewing all the information, better management decisions can be made. The return on investment can be determined in dollars per acre rather than on total production costs.

Uses of Precision Agriculture in the Agricultural System

Land preparation—GPS can be used to provide more accurate leveling of the seedbed for flood-irrigated lands. It can be used to provide more accurate control of agricultural machinery, reducing overlap and requiring fewer passes to perform a field operation.

Crop Monitoring, Pest Management, and Irrigation Water Management—At different times during the growing cycle, the crop can be monitored for moisture stress, insect infestation, and weeds. Tasks such as irrigation, spraying, and cultivation can be performed only on the areas of a field that require them.

Soil and Nutrient Monitoring—After soil fertility has been tested across a field, a GIS map can show the fertility of the soil, the soil type, and nutrient deficiency at different areas in the field. Soil amendments such as sulfur, lime or organic material and fertilizer can be applied only to areas that need them. When crop yields are compared with soil and nutrient information for specific areas, it may be possible to determine that certain crops are more suited to different soil types and would do better in fields with those soil types.

Conservation Practices—GIS information concerning soil productivity and erodibility could be used to control implements so the soil is not tilled in highly erodible areas.

Possible Uses of Precision Agriculture Techniques for Nurseries

Some precision agriculture techniques may not apply to nurseries because nurseries are much smaller than the typical farm. The nursery manager has a much better idea of the fertility of seedbeds, irrigation needs, and pest invasions than the typical farmer would have. Seedling lots are usually small. Hand markers can be placed to mark different lots. However, some possibilities do exist for use of precision agriculture techniques in nurseries.

Monitoring Source for Tree Seed—The seed source for seedlings should be located near the area where the seedlings are to be planted after they are taken from a nursery. The GPS position of the seed source would provide a manager information on where the seed was harvested. A database could be built recording potential seed sources and their positions for future use.

Outplacing Seedlings—It would be valuable to know where lots of different seedlings are placed in the forest. If different growing practices have been used for various seedlings, an easy way of monitoring seedling performance would be to observe their growth in the location where they were planted.

References

The following sources of information are not intended to be complete, nor do they represent any form of endorsement. Each source is easily available through the Internet and may offer additional links to other information. The Internet can be a valuable tool for gathering information, but the information should be used with discretion. Sites were valid as of July 1999.

"Variable Rate Technology: a State of the Art Review" University of Georgia. http://www.bae.uga.edu/dept/research/precision/rough.html

"Variable Rate Application Equipment for Precision Farming" R.L. Clark, R.L. McGuckin, Department of Biological & Agricultural Engineering, University of Georgia. http://www.bae.uga.edu/dept/research/precision/clark_vrt.html

"Table 1-List of Equipment That Has Been Used for Variable Rate Application" Department of Biological & Agricultural Engineering, University of Georgia. http://www.bae.uga.edu/dept/research/precision/addreses.html

Precision Agriculture-General

"Precision Farming: A New Approach to Crop Management," Stephen Searcy, Texas A&M University http://agprogram.tamu.edu/search/search.cgi

"Sensors vs. Map-Based Precision Farming," Mark T. Morgan, Purdue Agricultural and Biological Engineering Department, April 1995 http://pasture.ecn.purdue.edu/~mmorgan/PFI/graphic.html

Internet Precision Agriculture Links

"Precision Agriculture and Related Informational Resources," University of Georgia, NESPAL http://nespal.cpes.peachnet.edu/resources_links/precisionag

Oregon State University, College of Agricultural Sciences http://www.orst.edu/dept/hort/precag

Missouri Precision Agriculture Center http://www.fse.missouri.edu/mpac

Precision Farming Institute http://dynamo.ecn.purdue.edu/~biehl/SiteFarming

The Ag and Farm Search Engine http://www.joefarmer.com

PrecisionAg.com http://www.precisionag.com

Centre for Precision Farming, Cranfield University http://www.silsoe.cranfield.ac.uk/cpf/index.htm

The University of Sydney, Australian Centre for Precision Agriculture http://www.usyd.edu.au/su/agric/acpa

Farm From Space http://www.dtnearthscan.com

Ag Leader Technology http://www.agleader.com

Agriculture Online http://www.agriculture.com

Omnistar http://www.omnistar.com/article1.htm

ROCKY MOUNTAIN JUNIPER STUDY: PRELIMINARY RESULTS

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Barbour, J. 2002. Rocky Mountain Juniper Study: Preliminary Results. In: Dumroese, R.K.; Riley, L.E.; Landis, T.D., technical coordinators. National Proceedings: Forest and Conservation Nursery Associations—1999, 2000, and 2001. Proceedings RMRS-P-24. Ogden, UT: USDA Forest Service, Rocky Mountain Research Station: 59-66. Available at: http://www.fcnanet.org/proceedings/1999/barbour.pdf

Key Words

Seed treatment, seed germination, seed testing, weight separation, seed sizing

Rocky Mountain juniper (*Juniperus scopulorum* Sarg.) seed are hard to germinate in the nursery, containers, or laboratory because they have multiple dormancies. The seedcoat and prophylactic sheath surrounding the embryo impede water absorption. The embryo's epicotyl is not dormant; only the hypocotyl displays dormancy and requires cold stratification (Djavanshir and Fechner 1976).

Stratification of dormant seed involves three stages (Nikolaeva 1969). During the first stage an initial vigorous swelling of seed take place. Following full imbibition the second stage ensues. Enzymatic activity and hydrolysis of proteins and fats begins. Products from the hydrolytic process prompt the beginning of embryo growth, which constitutes the third stage. Growth activation occurs during stratification in two periods. Mitoses occurs at the end of warm stratification when seed open; whereas, the second activation of growth happens at the end of cold stratification, prior to germination.

This leads to a perennial nursery problem because germination cannot always be predicted. Weather patterns are not identical in every nursery that grows Rocky Mountain juniper. Southernmost nurseries may not receive enough cold weather to provide a sufficient cold stratification period for seed germination. In years when snowfall is not adequate to cover the beds, the seed dry out due to cold, dry, winter winds. Generally, outdoor stratification is not as efficient as constant temperature and moist laboratory stratification, except under conditions of continuous snow cover (Young and Evans 1976). When the seed dry out, they go into secondary dormancy, thereby inhibiting germination.

Multiple stratification regimes make it difficult to manage the seed sown in nursery beds. Past experience among nursery managers has shown that Rocky Mountain juniper seed germinate most uniformly when a warm stratification period precedes the cold stratification period (Meines 1965). Most nurseries plant the seed in July to provide for the warm stratification period. USDA Forest Service Bessey Nursery in Halsey, NE provides the seed an additional 6 months of cold stratification prior to summer sowing (Benson 1976). Summer sowing is not consistent or predictable, because so many things can go wrong before the seed germinate next spring.

At present, there is not a repeatable germination test that can be used to sow seed. An official laboratory germination procedure has not been established. Many of the seed have been found to be empty or to have low viability, which yields inconsistent laboratory results. A tetrazolium test is used as a substitute for germination tests, because it can be performed on the seed in a couple of days. The test measures seed viability but does not predict germination.

HYPOTHESIS

Interest has been shown in applying weight separation to Rocky Mountain juniper seed to improve germinability (Lee and others 1995). Lee (1996) used sodium chloride solutions to separate seed by density and significantly increased

germination over all density classes when compared to a control. In this study, mechanical weight separation was done with a gravity table.

Weight and size are confounded in seed, so seed must be sized before weight separation can occur. The gravity table is not designed to separate size and weight simultaneously. Separating low viability seed from high viability seed by using a gravity table increases germination potential. The general rule of thumb is that heavy seed germinate better then light seed. High viability seedlots have less variability and yield more consistent results in testing.

After the high viability seed are isolated, then a method to germinate the seed in the laboratory needs to be determined. Much research has been done on Rocky Mountain juniper; several laboratory treatments appear to work, but they are hard to compare in separate studies. Plus, many seedlots have low viability, which leads to inconsistencies in the data. When all germination treatments showing promise were incorporated into this study, a comparison could be made for optimum treatment selection. The next step would be to repeat the best laboratory treatments in the nursery for test correlation.

Seedlot Information

The Forest Service Bessey Nursery supplied a 30-pound lot of Rocky Mountain juniper seed for the study. The seed source was from western South Dakota and commonly used in the Great Plains. It has proved reliable, and it is relatively easy to obtain a steady seed supply. According to Van Haverbeke (1968), the Rocky Mountain juniper in western South Dakota is a hybrid of 50% Rocky Mountain juniper genes and 50% eastern redcedar (*Juniperus virginiana* L.) genes. Van Haverbeke (1968) postulates that the *Juniperus virginiana* population in eastern and central North America may be derived from the western juniper complex in the Rocky Mountains, especially from *Juniperus scopulorum*. The main migration pathway of pines in North America is southward and eastward (Mirov 1967). A similar migration pattern may equally apply to junipers, because they are associated with pine in the most xeric habitats of the western United States (VanHaverbeke and Read 1976).

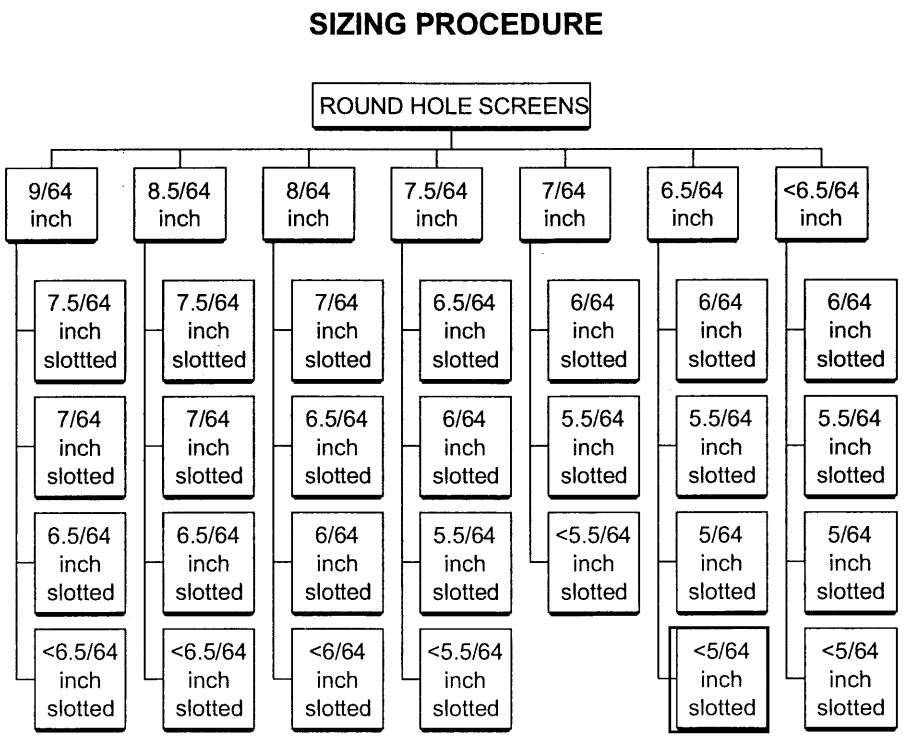


Figure 1. Sizing procedure developed at the National Tree Seed Lab.

SEED SIZING

The sizing procedure developed by Bob Karrfalt, director of the National Tree Seed Laboratory in Dry Branch, Georgia resulted in 27 sizes (Figure 1). The seed were first divided into 8 sizes using round hole screens ranging from < 6.5/64-inch to 9/64-inch in diameter. The eight sizes were then further subdivided with slotted whole screens ranging from < 5/64-inch to 7.5/64-inches in diameter. The round and slotted whole screens were increased in half size increments.

Following the sizing procedure, seed from the 27 sublots were tested for viability with a chemical staining test using 2,3,5-triphenyltetrazolium chloride. Live tissue stains red. The viability ranged from 61% to 79%, an 18% difference.

GRAVITY TABLE PROCEDURE

The Oliver® 30 DC gravity table was used to separate heavy weight seed from light weight seed. The Oliver® gravity table has a rectangular deck covered with screen that can be inclined and moved eccentrically, with air forced through the holes in the deck. The air creates a vertical stratification of the seed and eccentric shaking creates a horizontal stratification as the seed move down from the feed end to the discharge end of the deck. Heaviest seed are concentrated at the high deck side, light seed at the low side, and medium seed in the middle of the deck. There are three discharge chutes the seed fall through at the end of the deck creating three weight classes.

Seed samples, from each weight class, were x-rayed to check the table's operation. The light seed fraction was rerun over the table by itself and the seed was subdivided into medium, light seed and trash (Figure 2). The medium and lightweight seed were combined and labeled lightweight seed. The final result was four weight classes: heavy, medium, light, and trash for each of the 27 sizes (Figure 2). The procedure yielded 93 subsamples. Seed from each of the 93 sizes were tested for viability with a tetrazolium test. Table 1 is the average percent viability of subsamples by weight. The best seed was used to reduce variation and inconsistencies in the data.

Figure 2. **GRAVITY TABLE PROCEDURE**

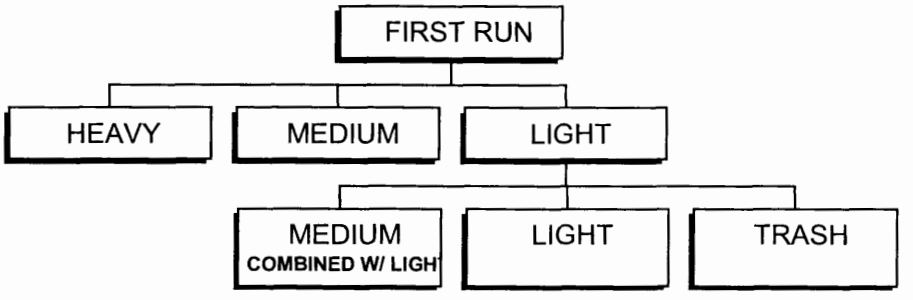


Table 1. Effect of weight separation before pregermination treatments.

Seed Weight	Percent Viability
Heavy	80
Medium	77
Light	65
Trash	53

Table 2. Selected seed lots.

Round	Slotted	Weight Class	Percent Viability
8.0/64	< 6.0/64	Heavy	81
7.5/64	6.0/64	Heavy	92
7.0/64	5.5/64	Heavy	94
6.4/64	5.5/64	Heavy	97
< 6.5/64	5.0/64	Heavy	92

Seedlot Selected

Following viability testing, seed from 5 out of the 93 subsamples, were selected and subjected to pregermination treatments (Table 2). The seed sizes ranged from large to small, all had high viability (above 80%), and all were in the heavy weight class.

Pregermination Treatments

Before seed treatments were applied, full imbibition was determined by selecting a seed sample from the seedlot. The initial moisture content of the seedlot was 9.9%. After a 4 day water soak at room temperature, the moisture content increased to 37% and did not increase further with longer soaking periods.

The five samples (Table 2) were subjected to 21 pregermination treatments (Table 3). Two hundred seed per treatment were used. The seed were placed in a plastic bag punctured with holes before initiating any treatment. In addition, seed from each of the five samples were allowed to imbibe room temperature water in an aerated, 5-gallon fish tank for up to 4 days before treatment (Pack 1921; Van Haverbeke and Comer 1985). The one exception was dry seed were immersed into the liquid nitrogen treatments. Seed receiving warm or cold stratification were placed into a plastic container filled with dampened peat moss. Warm stratification was performed at 72 °F (22 °C) and cold stratification at 37 °F (3 °C). Seed placed in a freezer were subjected to 20 °F (-7 °C). In the liquid nitrogen treatments, seed were subjected to the liquid, not the vapor, form of nitrogen at -321 °F (-196 °C). The accelerated aging chamber was set at 104 °F (40 °C). Chemical treatments included a 3% hydrogen peroxide soak and a 10,000-ppm citric acid soak (Van Haverbeke and Comer 1985).

Germination Procedures

Seed were examined periodically and considered ready for germination testing when a few of the radicles emerged: a majority of the seed were swollen and had cracked seedcoats. Seed were removed from the plastic bag, rinsed, and allowed to surface dry before planting in germination dishes. Eight germination dishes with 25 seed each were placed in a walk-in germination room at a constant 59 °F (15 °C) with 8 hours of light/16 hours darkness. The fluorescent lights emitted 750 to 1250 lux or 75 to 125 foot candles which was in accordance with the rules of the Association of Official Seed Analysts, 1999 section 4.9.e. Pack (1921) noted that after-ripened seed should be planted at temperatures below 59 °F (15 °C). Chadwick (1946) found that germination following stratification was best at 50 °F (10 °C) to 55 °F (13 °C) and germination was considerably retarded at temperatures above 65 °F (18 °C) to 70 °F (21 °C).

The clear, plastic germination dishes measured 4 1/2-inch wide by 6 1/2-inch long by 2 1/2-inches tall. Kimpak® was used as the growing medium, and each dish received 80 milliliters of water before planting the seed. Germination was considered complete after the radicle, hypocotyl, and cotyledons emerged. The dishes were examined weekly and germination recorded. Weekly and total cumulative germination percentages were calculated.

Results

The mechanical weight separation successfully stratified the Rocky Mountain juniper seed by weight. The seed, with the greatest germination potential, were separated from low potential germination seed, thereby improving the seedlot. The average viability by weight was 80% heavy, 77% medium, 65% light, and 53% trash (Table 1). There was a 27% viability difference between heavy and trash seed when averaged over size. The viability among all 93 sizes ranged from 36% to 97%, a 61% difference.

Five treatments produced the best germination (Table 4). Seed in treatment 17 germinated in cold stratification; this was the only treatment where cold stratification preceded warm stratification. Repeating the treatment may not be necessary, since it was Rietveld's (1989) best treatment on Rocky Mountain juniper seed. Rietveld's seed sources included collections from Meade County and Cheyenne River South Dakota, which is the same general area as this study's seed source. As further validation, the Forest Service Bessey Nursery uses a cold/warm/cold stratification regime.

The other four treatments had a warm stratification period followed by a cold stratification period. Van Haverbeke and Comer's (1985) recommended treatment (citric acid soak)

Table 3. Pregermination treatments.

Treatment Number	Treatment
1	3-day water soak, 26 weeks cold, 3 weeks warm
2	3-day water soak, 90 days in freezer, 13 weeks cold, 13 weeks warm, 5 weeks cold, 4 weeks warm (Afanasiev and Cress 1942; Rievtveld 1989)
3	1-day liquid nitrogen, 4-day water soak, 6 months cold
4	1 day liquid nitrogen, 4-day water soak, 1 month cold, 1 day liquid nitrogen, 5 months cold, 14 weeks warm, 4 weeks cold, 4 weeks warm
5*	liquid nitrogen 3 times with 4 weeks cold between, 21 weeks cold, 4 weeks warm, 8 weeks cold, 4 weeks warm, cold ongoing
6*	liquid nitrogen 4 times with 4 weeks cold between, 16 weeks cold, 9 weeks warm, 4 weeks cold, cold ongoing
7*	liquid nitrogen, 5 times with 4 weeks cold between, 12 weeks cold, 4 weeks warm, 4 weeks cold, 10 weeks warm, cold ongoing
8*	liquid nitrogen, 6 times with 4 weeks cold between, 7 weeks cold, 9 weeks warm, 9 weeks cold, 4 weeks warm, cold ongoing
9	liquid nitrogen 6 months, 9 weeks cold, 17 weeks warm
10	liquid nitrogen 2 months, 33 weeks cold, 9 weeks warm
11	accelerated aging chamber 7 days, 5 weeks cold, 13 weeks warm, 4 weeks cold
12	3-day water soak, 14 weeks cold, accelerated aging 7 days, 12 weeks cold, 12 weeks warm, 9 weeks cold
13	6-day 10,000 ppm citric acid soak, 6 weeks warm, 10 weeks cold (Van Haverbeke and Comer 1985; Cotrufo 1963)
14	4-day soak, 12 weeks warm, 13 weeks cold
15	90-minute hydrogen peroxide soak, 8 weeks warm, 13 weeks cold (Van Haverbeke and Comer 1985)
17	3-day soak, 16 weeks cold, 9 weeks warm, 9 weeks cold (Rietveld 1989)
18	3-day soak, 16 weeks cold, 10 weeks freezer, 14 weeks warm, 4 weeks cold, 4 weeks warm (Ananasiev 1955; Rietveld 1989)
19*	90-minute sulfuric acid soak, 27 weeks cold, 9 weeks warm, 9 weeks warm, 9 weeks cold, 4 weeks warm, cold ongoing (Djavanshir and Fechner 1976)
21	3-day soak, 16 weeks warm, 13 weeks cold (Clark Fleege's recommendation)†
23	24-hour liquid nitrogen dunk 3 times, 4-day soak, 2 weeks cold, 6 weeks warm for 2 seedlots, 15 weeks warm for 3 seedlots
24	5-day soak, used Georgia soil‡, 24 weeks cold, 15 weeks warm, 4 weeks cold

Treatments 16, 20, & 22 were deemed unnecessary so they were never performed.
*Clarke Fleege was the Bessey Nursery's nursery manager at time of experiment.
†Treatments 5, 6, 7, 8, 19 abandoned because seed did not show signs of germinating
‡Georgia soil used to test effect soil microorganisms may have on germination.

Table 4. Best treatments.

Treatment Number	Treatment Description
13	6-day 10,000 ppm citric acid soak, 6 weeks warm, 10 weeks cold
14	4-day soak, 12 weeks warm, 13 weeks cold
15	90-minute 3% hydrogen peroxide, 8 weeks warm, 13 weeks cold
17	3-day water soak, 16 weeks cold, 9 weeks warm, 9 weeks cold germinated in stratification during the second cold period
21	3-day water soak, 16 weeks warm, 13 weeks cold

Table 5. Germination results.

Subsample	Treatment Number							Viability
	3	9	13	14	15	21	24	(%)
< 6.5 x 5.0 H	6	6	14	12	43	59	0	92
6.5 x 5.5 H	12	9	31	66	45	57	26	97
7.0 x 5.5 H	13	9	30	64	46	54	0	94
7.5 x 6.0 H	13	15	27	46	45	52	0	92
8.0 x < 6.0 H	4	7	8	55	48	55	0	81
Average	10	9	22	49	45	55	6	91

was the fifth best treatment in the study. Treatment 21 (16 weeks warm, 13 weeks cold), proposed by Bessey Nursery's manager Clark Fleege, had the best germination of all treatments. Treatment 15 (3% hydrogen peroxide soak) was similar to Van Haverbeke and Comer's (1985) study, except they used 30% hydrogen peroxide. Their best hydrogen peroxide treatment (13 minute water soak, 30 minute hydrogen peroxide soak, 8 weeks warm stratification, 12 weeks cold stratification) yielded a 78.7% germination rate. Three of the five best treatments in this study were also the best treatments in other experiments.

The best treatments are not difficult to perform at the nursery. They can be used to augment the summer sowing program as insurance against a failed crop. In the event the summer sown seed do not come up, then the spring planted seed can be used to produce seedlings.

Several treatments (5, 6, 7, 8, 19) were abandoned when the seed was not ready to germinate after a year of pretreatment. Even if the treatments had worked, no one would use them because the treatments were impractical and they lasted too long. In treatment 19, the sulfuric acid carbonized the seed surface, thus prohibiting germination. Djavanshir and Fechner (1976) found that black carbon had to be removed by hand rubbing before seed would germinate. Carbon removal would be impractical when dealing with large seedlots.

The best treatments' germination ranged from 55% to 22% (Table 5). No germination results were reported for treatment 17. An accurate count could not be made because so much seed germinated in stratification. I was unable to determine when the seed had germinated during the second cold period and the seedlings had deteriorated into a gelatinous mess.

The heavy seed in each size class responded similarly to treatments resulting in a small variance around the mean. The majority of seed germinated in the first 2 weeks—signifying vigorous seed. Rapid germination is desirable in the nursery due to the many unforeseen environmental factors that can hinder seed germination.

Although viability of the five subsamples averaged 91%, the seed only germinated around 50% (Table 2). About 40% of the seed did not germinate, even though they stained red in the tetrazolium test. The tetrazolium test only indicated whether the seed was alive, not whether it was vigorous enough to germinate. The test did not predict

germination, but was used as a benchmark of seed quality. From past experience, nursery managers have been developing a target number of seedlings from the tetrazolium results.

Since the best treatments in this study were also the best in other experiments even when the seed had low germination, the process should work on medium and light weight seed classes. They may give a more variable response to treatments, due to the presence of more ungerminable seed in the sample. Freshly harvested and cleaned seed may not require as long a warm/cold stratification period as stored seed. With the periodicity of seed crops, Rocky Mountain juniper seed will have to be stored, so these treatments will apply to most of the seed being planted.

Future Recommendations

The first step is to try the best five treatments in a nursery. Will treatments act similarly in the nursery as they did in the laboratory where the seed were given the optimum conditions for germination? The germinator was set at a constant 59 °F with only small temperature fluctuations. Nursery beds' temperatures fluctuate greatly between day and night. The ambient temperature may not be at the optimum when seed are ready to germinate, therefore inhibiting germination.

The second step is to try the treatments on other seed sources. Treatments worked well on this seed source, but what about the more westerly sources where introgression with *Juniperus virginiana* has probably not occurred? Warm-moist stratification has not proved effective on enhancing germination of any juniper species where winter precipitation is dominant and summers are almost completely dry (Young and others 1981). Young and others (1981) have found that oxygenated, refrigerated water baths worked best for Utah juniper (*Juniperus osteosperma* Torr.) and western juniper (*Juniperus occidentalis* Hook.). This treatment may also increase germination for Rocky Mountain juniper and will be considered in the next stage of this study.

Statistical analysis of the data was not included in the nursery proceedings, but will be added in future reports.

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SOUTHERN FOREST NURSERY ASSOCIATION CONFERENCE

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CHLOROPICRIN, EPTC, AND PLANT GROWTH-PROMOTING RHIZOBACTERIA FOR MANAGING SOILBORNE PESTS IN PINE NURSERIES

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Abstract

The effects of preplant soil treatments and seed treatment on seedling production and soilborne pests were evaluated on loblolly pine (*Pinus taeda*) at three forest nurseries. Treatments were applied in 1998 at the Flint River Nursery (Byromville, GA) and at the Hauss Nursery (Atmore, AL). In 1999, treatments were applied at the Carter Nursery (Chatsworth, GA) and continued at Flint River Nursery. Soil treatments included 67% methyl bromide/33% chloropicrin at 350 lb/ac (MC33), EPTC (Eptam® 7-E), chloropicrin at 150 and 300 lb/ac (CH150 and CH300) and in combination with EPTC (CH150E and CH300E). At the Carter Nursery, a soil treatment of metam sodium at 80 lb/ac and chloropicrin at 150 lb/ac was added (M80/CH150). A seed treatment with the plant growth-promoting rhizobacteria (PGPR) *Paenibacillus macerans* was also evaluated with each soil treatment. In 1999, the EPTC herbicide treatment and PGPR seed treatment were reapplied to plots in the second-year crop at the Flint River Nursery.

Fumigation and EPTC treatments did not significantly affect seedling density at the three nurseries by the end of the growing season. At the Flint River Nursery in 1998, seedling root collar diameter was greater in the CH300 and CH150E treatments, and seedling top weight was greater in the CH300 and CH150 treatments. No other differences in seedling size were observed among treatments. Seedling density at the Hauss Nursery was greater in plots with the seed treatment compared with untreated seed. At the Carter Nursery, there were fewer seedlings (2/ft) in the seed treatment plots, and at the Flint River Nursery, the seed treatment reduced seedling height in 1998 and 1999. No observed disease or insect problems occurred in any of the nurseries.

The effect of fumigation with MC33 on soilborne *Pythium* and *Fusarium* spp. varied among the nurseries. In general, fumigation reduced populations of these fungi. Parasitic plant nematodes were reduced by all fumigants following fumigation at Carter Nursery. Nematodes were rarely observed in soil samples at the other nurseries. Nutsedge was seldom found in the fumigated plots at Flint River Nursery in 1998. By 1999 only the CH300 treatment had less nutsedge than the controls. EPTC was not effective for nutsedge control at Flint River Nursery. Populations of nutsedge at the Carter and Hauss Nurseries were very low.

Key Words

Fumigation, biological control, bareroot nursery

Forest tree nursery managers across the United States use soil fumigation to control fungi, insects, and weeds. Most forest nurseries fumigate with methyl bromide that contains either 2% or 33% chloropicrin (Smith and Fraedrich 1993). Alternatives to methyl bromide fumigation are necessary, as nursery managers confront the current phaseout of this chemical. Fumigation with 100% chloropicrin has been shown to be a promising alternative to MC33 (67% methyl bromide/33% chloropicrin) for control of soilborne fungi (Enebak and others 1990) as well as nematodes (Harris 1991) and insects (Breakey and others 1945). However, chloropicrin is not considered as effective as methyl bromide for the control of weeds such as nutsedge (South and others 1997). Although the herbicide EPTC (Eptam® 7-E) is registered for control of nutsedge in pine nurseries, few southern nurseries use this herbicide (South 1986). Damping-off is the most common disease problem cited by nursery managers in the South (Cram and Fraedrich 1996). Plant growth-promoting rhizobacteria (PGPR) are used in agricultural crops to promote plant growth (Ryder and others 1994), and are an emerging technology for tree production (Chanway 1997). PGPR seed treatment has been found to decrease damping-off of loblolly pine (*Pinus taeda*) seedlings (Enebak and others 1998), and to increase seedling emergence and growth (Enebak and others 1998; Holl and Chanway 1992; O'Niell and others 1992).

Pest management programs in the future will likely have to integrate various strategies to achieve the broad-spectrum control of pests that is currently provided by fumigation with MC33. This project examined combinations of EPTC, chloropicrin, and PGPR seed treatments as potential alternatives to MC33 for the production of loblolly pine (*P. taeda*).

Methods

The effects of preplant soil treatments on seedling production and soilborne pest problems were evaluated at the Flint River Nursery (Byromville, GA) and the E. A. Hauss Nursery (Atmore, AL) in 1998. Soil treatments consisted of MC33 at 350 lb/ac, EPTC at 7 pt/ac (E), 100% chloropicrin at 150 and 300 lb/ac (CH150 and CH300), and chloropicrin at both rates with EPTC (CH150E and CH300E). Tarps were used with all fumigants. Whole plots were split and a PGPR seed treatment of *Paenibacillus maceran* was applied at the rate of approximately 10^3 cfu/100 lb seed. In 1999, the study was continued at the Flint River Nursery, and a second study site was established at the Carter Nursery (Chatsworth, GA). An additional soil treatment of metam sodium at 80 lb/ac with chloropicrin at 150 lb/ac (M80/CH 150) was included at the Carter Nursery. A composite soil sample was obtained from each plot that consisted of 5 to 10 soil cores to a 6-inch depth. Soil samples were taken after fumigation and before lifting to assess nematodes and fungi. The presence of fungi in the soil was determined using various selective media: Komada's (Komada 1975), PARP (Kannwischer and Mitchell 1981), TMR (*Trichoderma*, pink medium) (Elad and others 1981) and PDA-T.

Three permanent history plots (1 x 4 ft) were established in each split-plot, and seedling counts were performed weekly for 5 to 6 weeks after sowing, at mid-season, and again prior to lifting. The presence of nutsedge and other weeds were documented within the first 6 weeks. At lifting, 45 seedlings per history plot were collected for assessment of seedling height (if not pruned), root collar diameter (RCD), and dry weight. All tests of significance were carried out at $\alpha = 0.10$. The Tukey's studentized range test was used for testing all multiple comparisons.

Results

Flint River Nursery

Fumigation and EPTC treatments did not affect seedling density (Table 1 and Table 2). In the first year, seedling RCD was greater in the CH300 and CH150E plots than the controls, and seedling top weight was greater in the CH300 and CH 150 plots. In both years, seedling heights were lower with the PGPR seed treatment than without treatment (Table 3 and Table 4). In 1999, a seed count at the time of sowing showed that one extra seed was sown per square foot; therefore, the greater seedling density with the seed treatment was discounted. All fumigated plots had less nutsedge than the controls in 1998, but only treatments with CH300 were significantly lower than the control plots in 1999 (Table 5). *Fusarium* and *Pythium* spp. were rarely isolated from fumigated soil immediately following application in 1998. Plant nematodes were rarely found in any of the treatment plots.

Table 1. Mean seedling density, size, and dry weight by soil treatment for loblolly pine at Flint River Nursery (Bryomville, GA) in November 1998

Treatments*	Density (ft^2)†	Root collar diameter (in)‡	Height (in)†	Root weight (oz)†	Top weight (oz)‡
CH300	22.0	0.180a	9.02	0.027	0.133a
CH150 E	21.5	0.175ab	7.69	0.027	0.107abc
CH300 E	21.0	0.173abc	7.73	0.026	0.110abc
CH150	22.2	0.172abc	8.83	0.026	0.121ab
MC33	22.5	0.163abc	7.67	0.023	0.103abc
E	22.6	0.158bc	8.10	0.023	0.092bc
Control	22.5	0.154c	7.57	0.022	0.082c

*CH300 = 100% chloropicrin at 300 lb/ac; CH150 = 100% chloropicrin at 150 lb/ac; E = EPTC (Eptam 7-E); MC33 = methyl bromide 67%/chloropicrin 33%.

†Means do not differ significantly ($P \leq 0.10$) from one another.

‡Means followed by the same letter do not differ significantly ($P \leq 0.10$) according to Tukey's studentized range test.

Table 2. Mean seedling density, size, and dry weight by soil treatment for loblolly pine at Flint River Nursery (Bryomville, GA) in January 2000

Treatments*	Density (ft^2)†	Root collar diameter (in)†	Height (in)†	Root weight (oz)†	Top weight (oz)†
CH300	22.5	0.141	9.55	0.024	0.094
CH300 E	22.3	0.139	9.69	0.024	0.092
CH150	21.7	0.146	10.08	0.025	0.099
CH150 E	21.1	0.145	9.70	0.025	0.095
MC33	22.5	0.139	9.75	0.021	0.094
E	22.9	0.140	9.90	0.024	0.089
Control	22.5	0.141	9.85	0.026	0.093

*CH300 = 100% chloropicrin at 300 lb/ac; CH150 = 100% chloropicrin at 150 lb/ac; E = EPTC (Eptam 7-E); MC33 = methyl bromide 67%/chloropicrin 33%.

†Means do not differ significantly ($P \leq 0.10$) from one another.

Table 3. Mean seedling density, size, and dry weight by seed treatment with *Paenibacillus macerans* for loblolly pine at Flint River Nursery (Bryomville, GA) in November 1998

Seed Treatment	Density (ft^2) *	Root collar diameter (in) *	Height (in) †	Root weight (oz) *	Top weight (oz) *
No	21.4	0.170	8.41a	0.024	0.109
Yes	21.7	0.166	7.76 b	0.025	0.105

*Means do not differ significantly ($P \leq 0.10$) from one another.

†Means differ significantly ($P \leq 0.10$) according to Tukey's studentized range test.

Table 4. Mean seedling density, size, and dry weight by seed treatment with *Paenibacillus macerans* for loblolly pine at Flint River Nursery (Bryomville, GA) in January 2000

Seed Treatment	Density (ft^2) *	Root collar diameter (in) †	Height (in) *	Root weight (oz) †	Top weight (oz) †
No	21.7 a	0.143	9.94 a	0.025	0.095
Yes	22.7 b	0.141	9.63 b	0.023	0.092

*Means differ significantly ($P \leq 0.10$) according to Tukey's studentized range test.

†Means do not differ significantly ($P \leq 0.10$) from one another.

Table 5. Nutsedge plants per ft^2 at Flint River Nursery (Bryomville, GA)

Treatments*	1998†	1999†
Control	1.75a	1.98a
E	0.69ab	1.73ab
CH150	0.02b	0.35ab
CH150 E	0.04b	1.00ab
CH300	0.00b	0.08b
CH300 E	0.00b	0.13b
MC33	0.00b	0.25ab

*CH300 = 100% chloropicrin at 300 lb/ac; CH150 = 100% chloropicrin at 150 lb/ac; E = EPTC (Eptam 7-E); MC33 = methyl bromide 67%/chloropicrin 33%.

†Means followed by the same letter do not differ significantly ($P \leq 0.10$) according to Tukey's studentized range test.

E. A. Hauss Nursery

Fumigation and EPTC soil treatments did not affect seedling density or seedling size (Table 6). Seedling density was higher in plots with the PGPR seed treatment, but seedling size was significantly lower with the seed treatment
(Table 7).

The population density of *Fusarium* spp. within the soil was less initially in the CH150 lb/ac and MC33 treatments; however, at the end of the year, only the CH300E treatment had a lower density of *Fusarium* spp. than the controls. The populations of *Pythium* spp. within the soil were lower initially in most fumigation treatments; however, at the end of the year, only MC33 was significantly lower than the controls. Plant nematodes were rarely found in any plots. The population of nutsedge plants was very low; however, there were no nutsedge plants observed in plots treated with MC33 or EPTC.

Table 6. Mean seedling density, size, and weight by soil treatment for loblolly pine at E. A. Hauss Nursery (Atmore, GA) in November 1998

Treatments*	Density (ft^2) †	Root collar diameter (in)†	Root weight (oz) †	Top weight (oz) †
CH300	22.2	0.188	0.030	0.111
CH300 + E	23.5	0.175	0.024	0.089
CH150 + E	23.1	0.178	0.027	0.095
CH150	23.3	0.180	0.024	0.105
MC33	23.0	0.180	0.027	0.098
E	23.8	0.172	0.028	0.092
Control	23.0	0.181	0.028	0.100

*CH300 = 100% chloropicrin at 300 lb/ac; CH150 = 100% chloropicrin at 150 lb/ac; E = EPTC (Eptam 7-E); MC33 = methyl bromide 67%/chloropicrin 33%.
†Means do not differ significantly (P ≤ 0.10) from one another.

Table 7. Mean seedling density, size, and weight by seed treatment with *Paenibacillus macerans* for loblolly pine at E. A. Hauss Nursery (Atmore, GA) in November 1998

Seed Treatment	Density (ft^2) *	Root collar diameter (in)†	Root weight (oz)†	Top weight (oz) *
No	22.5 b	0.181	0.028	0.103 a
Yes	23.8 a	0.177	0.026	0.095 b

*Means differ significantly (P ≤ 0.10) according to Tukey's studentized range test.
†Means do not differ significantly (P ≤ 0.10) from one another.

Carter Nursery

Seedling density was initially greater in the plots fumigated with M80/CH 150 than the control plots; however, by the end of the year these differences were no longer significant for either seedling density or size (Table 8). Seedling density was significantly less in plots with PGPR seed treatment compared to untreated seed (Table 9). There was a corresponding increase in seedling size with the reduction in seedling density in the seed treatments plots.

Table 8. Mean seedling density, size, and dry weight by soil treatment for loblolly pine at Carter Nursery (Chatsworth, GA) in November of 1999

Treatments*	Density (ft^2) †	Root collar diameter (in)†	Root weight (oz) †	Top weight (oz) †
CH300	20.3	0.201	0.034	0.123
CH150 E	19.4	0.197	0.033	0.109
CH300 E	20.5	0.201	0.031	0.120
CH150	19.6	0.201	0.036	0.116
M80/CH150	22.5	0.197	0.029	0.102
MC33	21.1	0.205	0.037	0.131
E	20.3	0.197	0.029	0.109
Control	20.5	0.197	0.032	0.109

*CH300 = 100% chloropicrin at 300 lb/ac; CH150 = 100% chloropicrin at 150 lb/ac; E = EPTC (Eptam 7-E); M80 = metam sodium at 80 lb/ac; MC33 = methyl bromide 67%/chloropicrin 33%.

Table 9. Mean seedling density, size, and dry weight by PGPR seed treatment with *Paenibacillus macerans* for loblolly pine at Carter Nursery (Chatsworth, GA) in November 1999

Seed Treatment	Density (ft^2) *	Root collar diameter (in)†	Root weight (oz) *	Top weight (oz) *
No	21.6 a	0.195	0.031 b	0.109 b
Yes	19.4 b	0.203	0.034 a	0.120 a

*Means followed by the same letter do not differ significantly (P ≤ 0.10) according to Tukey's studentized range test.
†Means do not differ significantly (P ≤ 0.10) from one another.

The population density of *Fusarium* spp. was significantly lower in CH300 plots than the unfumigated EPTC plots after fumigation. The population density of *Pythium* spp. were significantly less in the CH300, M80/CH150, and MC33 treatments than the controls immediately following fumigation; however, only the M80/CH150 treatment had significantly lower levels by the end of the year. Parasitic plantnematodes were reduced by all fumigants, but by November 1999 there were no significant differences among treatments. Nutsedge plants were rare at Carter Nursery.

Discussion

The various fumigation treatments had little influence on seedling bed densities, and differences in seedling size only occurred at the Flint River Nursery, where seedling size was greater in some of the chloropicrin treatments than the controls in the first year. This lack of consistent differences among treatments was most likely due to the absence of insect and disease problems at any of the nurseries. Although fumigation has primarily been used for pest control in forest-tree nurseries, the practice can also affect soil nutrient availability. Fumigation has been shown to influence the availability of nitrogen (Hansen and others 1990), manganese (Alexander 1967), and phosphorus (Ingestad and Molin 1960). In addition, fumigation can also change the soil microbiota (Hansen and others 1990) and favor the presence of fungi that may be beneficial for seedling growth (Ingestad and Nilsson 1964). The increase in seedling quality in the first year following fumigation at the Flint River Nursery may have been related more to changes that occurred to nontarget soil microbiota and soil chemical factors than the actual control of pests. The PGPR seed treatments can be beneficial to loblolly pine seedling emergence and growth as well as reduce seedling growth (Enebak and others 1998). The complex interactions of PGPR with the seedling and the soil environment have led to variable results (Enebak and others 1998).

In the current study, the PGPR seed treatments in the three nurseries resulted in inconsistent effects on seedling density and quality. While the PGPR seed treatments increased seedling density at the Hauss Nursery, the treatments had the opposite effect at the Carter nursery and no affect at the Flint River Nursery. The effect of seed treatment on seedling size was largely confounded by seedling density, except at the Flint River Nursery where seedling height was significantly less in the PGPR treatments. A better understanding is needed of the mechanisms by which PGPR seed treatments affect seed germination and seedling growth in southern pine nurseries if this treatment is to be operationally applied. Most weeds, with the exception of nutsedge, were effectively managed through the operational weed control programs used at the nurseries. Populations of nutsedge varied greatly among the nurseries, with the Flint River Nursery having the greatest population and the Carter Nursery having almost none. The effectiveness of fumigants and EPTC to control nutsedge may be tied to soil texture. In the sandy-textured soil of the Flint River Nursery, chloropicrin provided good control of nutsedge, while EPTC did not. The opposite trend occurred in the heavier textured soils of the Hauss Nursery, where nutsedge was observed in plots treated with chloropicrin and not in lots treated with EPTC.

The success of fumigation in reducing soilborne fungi may also be tied to soil texture. The population densities of *Fusarium* and *Pythium* spp. were initially low in all fumigated plots of the Flint River Nursery. In the heavier soils at the Hauss and Carter nurseries, the success of fumigation in reducing the population of *Fusarium* spp. was variable. Lower populations of *Pythium spp.* were obtained by most of the fumigants initially in the nurseries with heavier soils; however, by the end of the growing season only MC33 of M80/CH150 maintained a significant difference.

Chloropicrin, alone and in combination with metam sodium, reduced soilborne pests as well as MC33 in most cases. The amount and type of fumigants needed for control of soilborne pests vary among nurseries depending on their soil condition and pest problems. In this study, chloropicrin at the lower rate was adequate for reducing soilborne fungi and nutsedge in the sandier soils at the Flint River Nursery. In the heavier textured soils of the Carter Nursery, the higher rate of chloropicrin improved the control of soilborne fungi. Evaluations of the treatments are continuing for a third year at the Flint River Nursery and for a second year at the Carter Nursery to determine the value of these treatments over 2 or 3 years.

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SEEDLING PRODUCTION AND PEST PROBLEMS AT A SOUTH GEORGIA NURSERY

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Abstract

Pine seedling production and pest problems were evaluated in methyl bromide-fumigated and nonfumigated plots in two fields at a South Georgia nursery. In one field, fumigation increased loblolly pine seedling bed density in only 1 of 4 years. Seedlings were often significantly larger in fumigated than nonfumigated plots. In the other field, no differences were observed between treatments for bed densities or morphological characteristics. The primary pest problem in nonfumigated plots was nutsedge; most other weeds were controlled through the nursery's weed control program. Plant-parasitic nematode populations did not increase over time and were not viewed as a problem. *Macrophomina phaseolina* was rarely recovered from soil or roots. Although *Fusarium* spp. and *Pythium* spp. were more common in soil and on roots in nonfumigated than fumigated plots, evidence of disease was rare. At present, studies have not found isolates of *F. oxysporum* that are pathogenic to southern pines. A recent study conducted in a fallow field found that single and multiple applications of glyphosate were effective for control of nutsedge.

Key Words

Experimental design, research, bareroot nursery, container nursery, statistics, pest biology, fumigation, herbicides

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Methyl bromide has been identified as an ozone-depleting chemical, and a complete phaseout of the production and consumption of this chemical is scheduled to occur by 2005 in accordance with the United States Clean Air Act and the Montreal Protocol (Environmental Protection Agency 1999). The loss of this chemical will require a better understanding of pest problems that affect pine production in southern nurseries and the development of alternative pest-management strategies. In the future, it is likely that nursery managers will have to rely on more complex integrated pest management programs that are based on information about the biology of the pests and a variety of strategies to provide for their prevention and control.

The Flint River Nursery (Byromville, GA) was established by the Georgia Forestry Commission in 1986. Since that time, fumigation with methyl bromide has been a standard practice for weed control and to ensure the elimination of possible soilborne pathogens and plant-parasitic nematodes. Studies have been underway at this nursery since 1995 to better understand the types and extent of pest problems that could adversely affect pine seedling production if fumigation with methyl bromide was not utilized, and to develop cost-effective means for pest control. In this paper, we present information on three studies that provide an initial framework for an integrated pest management program that could ultimately reduce dependency on fumigation. These studies include: 1) an evaluation of seedling production and pest problems in fumigated and nonfumigated soil in two fields; 2) results of pathogenicity tests of *Fusarium oxysporum* Schlecht. isolated from soil and roots; and 3) an evaluation of the

effectiveness of glyphosate for the control of nutsedge.

Materials and Methods

Evaluation of seedling production and pest problems

The studies were established in two compartments at the Flint River Nursery in the spring of 1995. Compartment 8S (C8S) was regarded as a problem area because seedling losses were observed in this field in the late 1980's and early 1990's. The precise cause of the losses was not known, but disease due to fungi and nematodes was suspected. The field was removed from operational production and since then had not been fumigated. Compartment 4N (C4N) was being placed back into production in May of 1995 after being in cover crops for 2 years. Three blocks were used in C8S. Each block consisted of the area between two irrigation risers and consisted of six nursery beds. The blocks were divided evenly into two plots, and each plot was randomly assigned to either the "fumigation" or "no fumigation" treatment. Each plot was approximately 76 m long and 5 m (three planting beds) wide. Three plots were fumigated with methyl bromide/chloropicrin (67%/33%) (MBC) at 393 kg/ha in the spring of 1995; the other three plots were not fumigated. All plots were sown operationally with loblolly pine (*Pinus taeda* L.) seeds in early May of 1995. The study was repeated in the same plots in 1996, 1997, and 1998, with MBC reapplied in the spring of each year before sowing.

Three blocks were also used in C4N and plots were established as described for C8S. Plots were approximately 38 m long and 5 m (three planting beds) wide. Three of the plots were fumigated with MBC in 1995; the other three plots were not fumigated. The field was sown operationally with loblolly pine seeds. The study was repeated in 1996, but fumigated plots were not refumigated. All plots were sown with slash pine seeds in 1996.

All seedlings were grown under operational conditions. Standard weed control practices included presowing applications of fomesafen (REFLEX®) and oxyflourfen (GOAL®) and weekly applications of oxyflourfen after the seedlings were 6 weeks old until approximately the middle of August.

Seedling measurements and samples were obtained from the center bed in each study plot. Three permanent history subplots, each 0.3 by 0.6 m, were randomly established in each plot immediately after seed sowing in order to monitor and evaluate seedling bed density. Live and dead seedlings were normally counted at 7 to 10 day intervals during the first 6 to 8 weeks after planting. A final assessment was conducted during the fall of each year. Morphological characteristics (root collar diameter, shoot height, and shoot and root weight) were evaluated in the fall or winter following seed sowing. For this study, only the root collar diameter will be presented and discussed. Each year, seedlings were lifted from three 0.3- by 0.6-m sample plots selected at random locations over the length of each plot. Morphological characteristics were measured on 20 to 75 seedlings per plot each year.

Pine root systems were evaluated yearly at mid-season (July-August) and at the end of the growing season (October-November) for species of *Pythium*, *Fusarium*, and other potentially pathogenic fungi using several selective media (Kannwischer-Mitchell and others 1994). The number of colony forming units (CFUs) of *Fusarium* spp. present in fumigated and nonfumigated soil was assessed immediately after fumigation in May of 1995 and again in May of 1998. The presence of the charcoal root rot fungus, *Macrophomina phaseolina* (Tassi) Goid. in soil was assessed (Kannwischer-Mitchell and others. 1994) on all plots in 1995 prior to fumigation, just after fumigation, and at the end of the season. When observed, samples of dead and dying seedlings were collected, examined, and plated on agar media to determine fungal associations.

Nutsedge (*Cyperus* spp.) plants were counted at least once yearly during 1995, 1996, and 1998 on the three 0.3 by 0.6-m permanent history subplots in each treatment plot. Plant-parasitic nematodes were assessed twice yearly during the growing season in all treatment plots in C8S. Nematodes were only assessed in 1995 in C4N. Nematodes were either extracted from soil using the centrifugal-flotation technique (Hooper 1986) and evaluated to genus, or soil samples were processed by the Cooperative Extension Services at the University of Georgia.

Pathogenicity Tests

Isolates of *F. oxysporum* obtained from roots and soil were tested for pathogenicity to pine seedlings grown in containers in a growth chamber at 22 to 24 °C. Inoculum was produced by growing the *Fusarium* isolates on sterilized wheat grains for 14 to 28 days. Four grams of the inoculum were ground and mixed thoroughly with 1,000 grams of nursery soil that had been microwaved to eliminate potential pathogens. Five germinated loblolly or slash (*Pinus elliottii* Engelm. var. *elliottii*) pine seeds were planted in each container. Three containers (15 seedlings total) were used for each fungal isolate and pine species. In order to ensure that pathogenicity could be detected with our system, we also tested isolates of *F. subglutinans* (Wollenw. & Reinking) Nelson, Toussoun & Marasas f. sp. *pini* known to be pathogenic to pine. These isolates had been obtained from contaminated longleaf pine (*P. palustris* Mill.) seeds and diseased longleaf pine seedlings. Six sets of control containers, each set consisting of three containers (18 total containers), were established for each pine species. Soil in control containers was mixed with ground, sterile wheat grains and planted with germinated pine seeds as previously described. Some mortality was observed in control containers and often varied with the experience level of the individual setting up the test. This mortality was most likely due to injury to seedlings that occurred during their transplanting from germination containers.

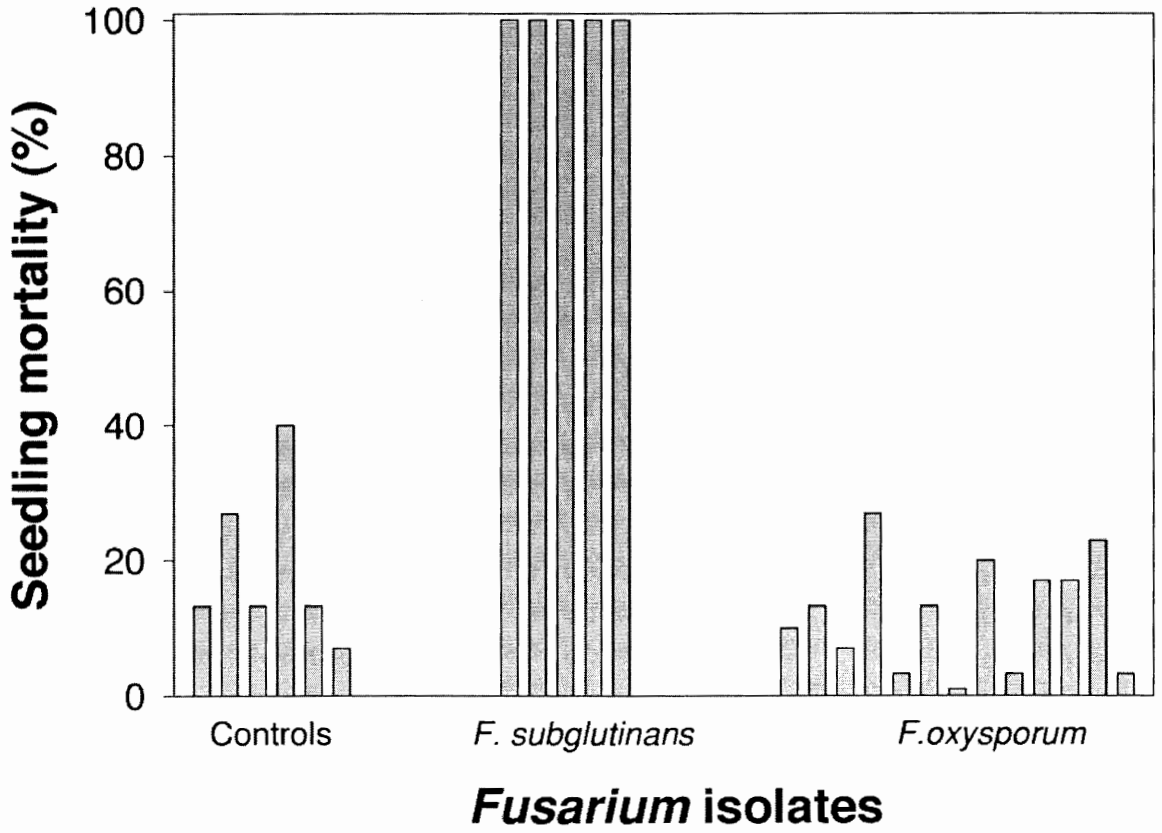


Figure 1. Percentage of seedling mortality in pathogenicity tests of isolates of Fusarium oxysporum *and* F. subglutinans *f. sp* pini. *Each bar represents percent mortality associated with one isolate and is based on results with 30 seedlings (15 slash pine, 15 loblolly pine) in 6 containers (5 seedlings/container) for each isolate.*

Nutsedge control with glyphosate

The effect of repeated glyphosate applications on nutsedge plants was examined during 1999. A 3.7-ha field was left fallow in spring of 1999. The field had been previously fumigated in 1995; however, nutsedge had recolonized throughout this field since that time. Purple nutsedge (C. *rotundus* L.) was the primary species in this field, although yellow nutsedge (C. *esculentus* L.) was also noted. The field was divided into 12 plots each approximately 213 m long by 10 m wide. Plots were randomly assigned to one of four treatments that consisted of glyphosate applications applied zero, one, two or three times during the growing season. Glyphosate was applied at 4.65 L/ha to plots on the following schedule: one application-14 June; two applications -14 June and 2 September; and three applications-14 June, 2 September, and 14 October. Originally the spray schedule was to be at 6-week intervals, but this schedule had to be modified due to drought and water shortages during the summer of 1999. The number of nutsedge plants was counted on six 0.3- by 0.6-m subplots per treatment plot on 20 October 1999 and again on 22 March 2000. At the October evaluation, soil was excavated from three 0.3- by 0.6-m subplots to a 15-cm depth and sieved to extract nutsedge tubers. Tubers were counted and treated to induce sprouting using the technique of Teo and Nishimoto (1973). Tubers were placed in germination boxes with moistened germination paper, and the percentage of sprouted tubers was evaluated after 2 weeks.

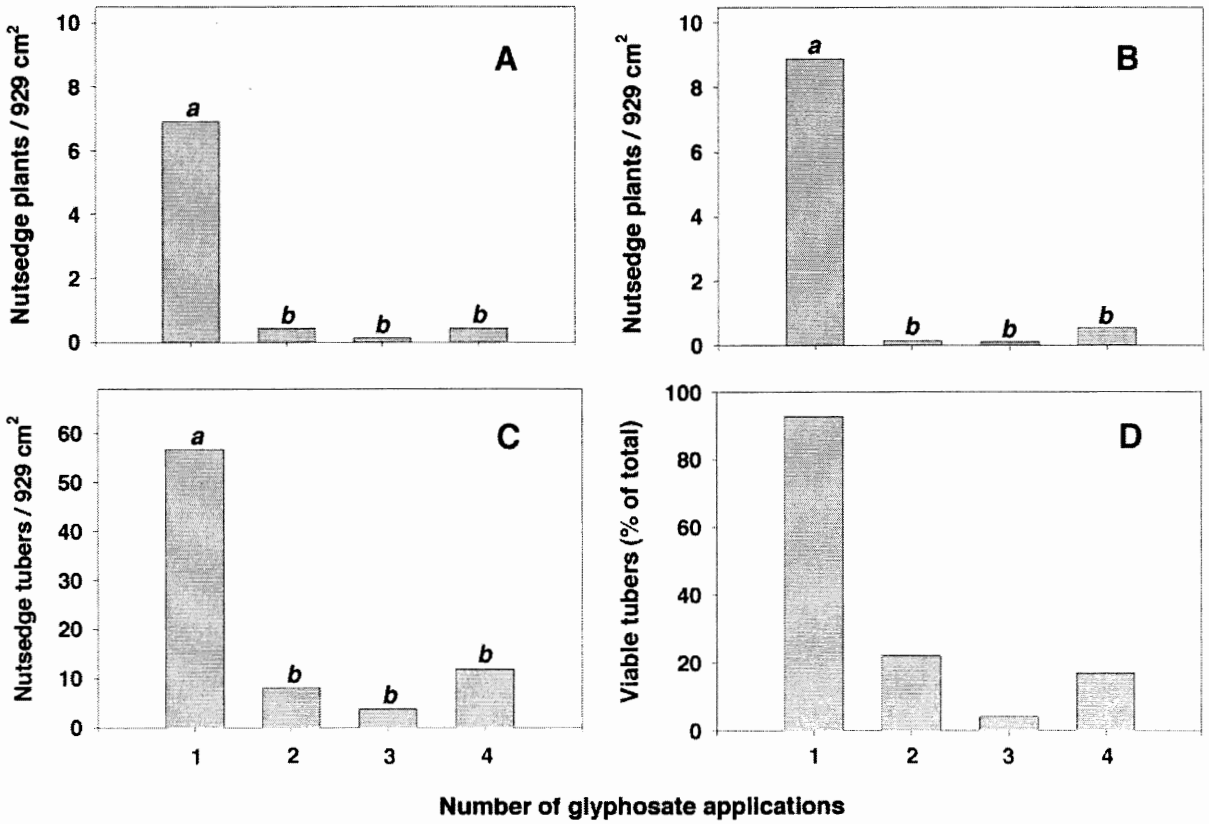


Figure 2. Evaluation of glyphosate for nutsedge control in a fallow field during 1999 with zero, one, two or three applications of herbicide. Effects of glyphosate on (a) *number of plants per 929 cm² on 20 October 1999,* (b) *number of plants per 929 cm² on 22 March 2000,* (c) *number of tubers per 929 cm² collected on 20 October 1999, and* (d) *percentage of viable tubers collected on 20 October 1999. Glyphosate was applied at 4.65 L/ha (2 qts/A) to plots on the following schedule: one application - 14 June, two applications - 14 June and 2 September, and three applications - 14 June, 2 September and 14 October.*

Discussion

Reductions in seedling bed densities or root collar diameters were noted in nonfumigated plots in C8S during most years, but no differences were noted in seedling quantity and quality between fumigated and nonfumigated treatments in C4N. The need for fumigation to prepare for seedling production can be questioned in the latter field.

Table 1. Mean number of loblolly pine seedlings per 929 cm^2, root collar diameter, and mean number of nutsedge plants per 929 cm^2 in methyl bromide-fumigated and nonfumigated plots in Compartment 8S at the Flint River Nursery during 1995, 1996, 1997, and 1998.

Year	Treatment	Seedlings/ 929 cm^2		Root Collar Diameter (mm)		Nutsedge Plants/ 929 cm^2	
1995	Fumigation*	25.6	a†	4.4	a	0.6	a
	Control	25.4	a	3.4	b	14.9	b
1996	Fumigation	24.4	a	4.1	a	0	a
	Control	20.0	b	4.0	a	16.4	b
1997	Fumigation	28.0	a	4.3	a	-	
	Control	26.6	a	3.4	b	-	
1998	Fumigation	23.1	a	5.6	a	0	a
	Control	23.6	a	5.2	a	22.3‡	b

* Plots were fumigated yearly in March or April.

† Means within year followed by a different letter differ at the P≤0.1 level.

‡ Measurement was made in May 1998. Nutsedge appeared chlorotic with some foliar dieback. Symptoms became progressively worse through May and June. In July 1999, the mean number of living nutsedge plants was only 5.4 per 929 cm^2.

Table 2. Mean number of pine seedlings per 929 cm^2, root collar diameter, and mean number of nutsedge plants per 929 cm^2 in methyl bromide-fumigated and nonfumigated plots in Compartment 4N of the Flint River Nursery during 1995 and 1996.

Year	Treatment	Seedlings/ 929 cm^2		Root Collar Diameter (mm)		Nutsedge Plants/ 929 cm^2	
1995*	Fumigation†	26.3	a‡	4.1		0.1	a
	Control	27.4	a	4.1§		2.2	b
1996	Fumigation	24.9	a	4.3	a	0.7	a
	Control	23.9	a	4.4	a	3.6	b

* Loblolly pine grown in 1995 and slash pine in 1996.

† Plots were fumigated only once in April of 1995.

‡ Means within year followed by a different letter differ at the P≤0.1 level.

§ One nonfumigated plot operationally lifted before final end-of-year evaluation.

The lower number of loblolly pine seedlings in nonfumigated compared to fumigated plots in C8S during 1996 may have been due to pre-emergence damping-off, although we do not have direct evidence for this. Seeds sown at the nursery were routinely treated with thiram, and a captan soil drench was applied at the time of sowing; both treatments are effective in controlling damping-off (Hodges 1962). In addition, differences between treatments were not observed in subsequent years. Although damping-off is one possible explanation for the observed difference in 1996, it is not inconceivable that some variation in sowing rate may have occurred among plots that could have contributed to the observed difference.

Competition from nutsedge was the most likely cause of the reductions in the size of loblolly pine seedlings. The lack of differences in size of seedlings between treatments in 1998 may have been related to the chlorosis, stunting, and eventual premature dieback of nutsedge plants during the spring and summer. We cannot explain the cause of the nutsedge decline. Personnel at the nursery indicated that they used fomesafen operationally in all pine beds as they had in previous years. Fomesafen is known to control yellow nutsedge but is not listed as effective on purple nutsedge. No effects of this herbicide on nutsedge had been observed in the 3 years prior to 1998, although nursery personnel indicated that the herbicide had provided control of nutsedge in other fields prior to initiation of this study. Nursery records indicated that no other herbicides except oxyflourfen were used in this field.

The lack of significant pest problems other than nutsedge in this study was somewhat unexpected. Nursery personnel thought the study area in C8S experienced nematode and soilborne disease problems in the past, and through continuous production of pines, these problems were expected to develop. This was not the case. Routine fumigation with methyl bromide has been regarded by many managers as essential for the prevention of soilborne diseases (Cram and Fraedrich 1996; Fraedrich and Smith 1994), but throughout this and other recent studies (Barnard and others 1996; Carey 1996; Carey 1998) there has been little evidence of soilborne diseases in nonfumigated areas. Considerable changes have occurred in forest-tree nursery operations since nurseries first began using methyl bromide fumigation in the post World War II era. Since that time, highly selective and effective herbicides have been developed (South 1979; South 1986). In addition, newer nurseries have been placed on sites with soils that are better drained and sandier textured than nurseries in the past (Boyer and South 1984). Many other changes have occurred with respect to practices such as types of cover crops used, seed quality, and fertilization (May 1980; Wakeley 1954). Together, these changes may have reduced the presence of pathogenic soilborne fungi, enhanced seedling growing conditions, and reduced the susceptibility of seedlings to many of the opportunistic soilborne pathogens that caused seedling losses in the past.

Nutsedge is a common weed problem in many southern forest-tree nurseries (Cram and Fraedrich 1996; Fraedrich and Smith 1994). Nutsedge has also been the primary pest problem in many studies that have examined alternatives to methyl bromide (Carey and South 1999; Dwinell and Fraedrich 1998; South and others 1997). Several studies have demonstrated the efficacy of glyphosate for nutsedge control in agricultural fields (Cools and Locascio 1977; Zandstra and others 1974). South (1984) indicated that glyphosate was effective for eradication of nutsedge in fallow fields. In our test at the Flint River Nursery, glyphosate proved very effective for nutsedge control in a fallow field that had been fumigated in recent years but where nutsedge had become reestablished. As noted in a study by Zandstra and Nishimoto (1977), glyphosate not only killed aboveground portions of purple nutsedge plants, but many tubers as well. Where fields can be left fallow for a summer, the use of glyphosate may provide a cost-effective alternative to routine fumigation with methyl bromide. The use of glyphosate in nutsedge-infested areas that border production fields may also help to reduce the rate of reintroduction of this weed into seedbeds.

Fusarium oxysporum has long been implicated in damping-off and root rot problems of pine in the South (Hodges 1962) and elsewhere in the United States (James and others 1991; Juzwik and others 1999). *Fusarium oxysporum* is commonly isolated from asymptomatic roots of crop plants, and nonpathogenic strains can be aggressive root colonizers (Gordon and Martyn 1997). Research

in western North America has indicated that there may be pathogenic and nonpathogenic strains of *F. oxysporum* in soils at conifer nurseries (Bloomberg 1976). In our studies at the Flint River Nursery, *F. oxysporum* was frequently isolated from soil and roots of seedlings, but at this time we have been unable to document the presence of pathogenic strains of this fungus. More needs to be learned about the biology of *Fusarium* spp. that occur in southern pine nurseries and their potential for causing disease losses.

The development of integrated pest management programs in the future will require specific knowledge of the pest problems that affect seedling production at any particular nursery, precise information on factors that affect the development of these problems, and knowledge about practices to prevent and control them. While weed control is possible in nurseries through an integrated program that does not rely on fumigation (South 1979), no such claims can presently be made for control of soilborne diseases and nematodes. Although research on finding cost-effective alternatives to fumigation for weed control have been constant since the 1970s, research on soilborne diseases and nematodes declined greatly. This may be due, in part, to a philosophy of research organizations that soilborne disease and nematode problems in nurseries were a low priority because most nurseries routinely fumigate with methyl bromide. With the pending loss of methyl bromide, the shortsightedness of this philosophy is now apparent. Managers that have employed fumigation routinely since the establishment of their nurseries may not be aware of the potential for disease and nematode problems at their location. In the short time that remains before methyl bromide is withdrawn from use, it is imperative that managers acquire information on the potential for disease and nematode problems at their nursery. Through these efforts a manager can better determine which pesticides will be needed in the future, evaluate the frequency at which they will be needed, and determine the timing at which they will be most effective. One method to gain this experience is to establish nonfumigated, control plots in fields that are to be fumigated. However, it is imperative that weed problems be considered in advance and the best possible weed management practices be utilized for nutsedge and other difficult-to-control weeds before plot establishment.

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Fungi Associated with Longleaf Pine Containers Before and After Cleaning

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Abstract

Soil was collected from used containers before and after they were cleaned at four nurseries that produce longleaf pine seedlings. The nurseries were located in Florida (FL), Georgia (GA), North Carolina (NC), and Mississippi (MS). The GA and MS nurseries used 5% and 10% bleach (sodium hypochlorite), respectively to clean containers, while the NC nursery used chlorine (5 g/L). The FL nursery did not clean their containers. *Fusarium* spp. were routinely isolated from the residual container soil; no *Pythium* spp. or *Phytophthora* spp. were isolated. The most common *Fusarium* spp. isolated were *F. oxysporum*, *F. proliferatum*, and *F. solani*. The average number of *Fusarium* colony forming units (cfu) per container cavity was much higher for FL (2,752 cfu) than for the other nurseries (49 to 309 cfu). No cleaning method was effective in eliminating *Fusarium* inoculum. Pathogenicity tests with F. *proliferatum* and *F. oxysporum* from MS resulted in a significant amount of cankers and some mortality of longleaf pine seedlings. *Fusarium proliferatum* from FL, GA, and NC caused a mild cankering response. Isolates of *F. proliferatum* from MS caused damping-off of germinating seedlings. Low levels of *F. proliferatum* were isolated from unused potting soil at the GA and NC nurseries, but none of these isolates were pathogenic.

Key Words

Container sanitation, soil testing, pathogenicity, container nursery, longleaf pine

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The practice of cleaning seedling containers before reuse is standard at most nurseries. Growers sanitize containers to reduce the potential for transfer of pathogens to the next seedling crop (Dumroese and others 1990). Andrew's Nursery in the state of Florida is one nursery that has not practiced cleaning containers as a standard treatment. The nursery is interested in maintaining beneficial fungi in their containers (for example, mycorrhizae), and tries to maintain as much soil as possible in the containers after seedling removal. The incidence of disease development has not differed between used and new containers in the FL operation. Containers at the other three nurseries are washed with bleach or chlorine.

Information is lacking on the fungi associated with used containers producing longleaf pine seedlings, and on the effectiveness of cleaning containers. In the northwestern United States and British Columbia, researchers found treatments with a bleach solution did not eliminate fungi from the used containers (James and others 1988, Sturrock and Dennis 1988). Information has not been available on the efficacy of chlorine as a container treatment. Some Southern nursery managers have expressed concern about the effectiveness of their cleaning technique on containers and about the potential for pathogenic fungi being introduced into containers from fresh potting soil. Because of these concerns, the objectives of this study were to: 1) evaluate the fungi associated with soil collected from used containers; 2) evaluate the *Fusarium* spp. associated with unused potting soil; and 3) test the fungi for pathogenicity.

Methods

Samples were collected from used containers from Claridge Nursery in Goldsboro, North Carolina (NC), T.W. Earle Nursery in Statesboro, Georgia (GA), Andrew's Nursery in Chiefland, Florida (FL), and W.W. Ashe Nursery in Brooklyn, Mississippi (MS). The used containers were sampled twice before they were cleaned. The first sampling occurred within a day of seedling removal. The second sampling occurred 2 to 3 weeks after seedling removal. A final sample of residue soil was collected after the nurseries operationally cleaned their containers. Six containers (12 for the MS nursery) were randomly selected for each of the precleaning samples, and 10 containers were randomly selected following cleaning. Soil particles retained on the surface of the containers were removed with a bristle brush. Samples were placed in plastic bags and stored at 3 °C for up to 1 week.

A 1-ml soil dilution of 0.1 grams of soil in 200 ml of cooled sterile water with 0.25% agar was placed on 10 plates of 2 selective medias. The selective medias were an Oomycetes media (Kannwischer and Mitchell 1981) and a *Fusarium* media made with PCNB (Nelson and others 1983). Only the *Fusarium* media was used with the postcleaning soil samples. The population of fungi in soil samples was based on the colony forming units (cfu) per gram of soil (wet weight). The dry weight of soil was not determined due to the small amount of soil collected. Only *Fusarium* spp. were recovered from soil collected before the containers were cleaned. Four colonies of *Fusarium* spp. were selected for identification by rotating the plate clockwise and sampling the first colony in the lower half of each quarter. All *Fusarium* spp. were single-spored and placed on carnation and PDA agar for identification.

Pathogenicity tests were conducted on *Fusarium* isolates from soil sampled after cleaning and from the fresh potting soil. No more than four isolates were tested for each *Fusarium* sp. Five 2-month-old longleaf pine seedlings were inoculated for each isolate. The resulting canker lengths were measured after 6 months. The cause of seedling mortality or cankers was determined from diseased tissue by isolation on PCNB media and transferring the fungi to carnation agar for identification.

Fusarium isolates from FL, GA, and MS were evaluated for their ability to cause damping-off. The wheat berry method used by Pawuk (1981) was modified to infest soil. Two randomly selected isolates of each *Fusarium* sp. from each nursery were grown on 10 grams of sterilized wheat berries soaked in 12 ml water. The two isolates were combined, ground-up and added to sterilized potting soil at a rate of 1:10 by weight. Ten germinating seedlings were placed in the soil. The cause of seedling mortality was determined by using PCNB media and transferring the resulting fungi to carnation agar for identification.

Results

Fusarium spp. were routinely isolated from the residual soil of used containers prior to cleaning. *Pythium* and *Phytophthora* were not isolated from used containers. No attempt was made to isolate *Pythium* and *Phytophthora* from postcleaning and potting-soil samples. There was no clear trend in the numbers of *Fusarium* cfu/g soil of the precleaning samples (Table1). At the MS and NC nurseries, the number of *Fusarium* cfu/g was much less in the postcleaning than the precleaning evaluations. At the GA nursery, the number of *Fusarium* cfu/g in the postcleaning was greater than the 3-week storage and less than the no storage precleaning evaluations. The FL *Fusarium* cfu/g soil was greater in the last sample before sowing than the first two samplings following seedling removal. *Fusarium* spp. were isolated from the unused potting soil at the GA and NC nurseries.

Table 1. *Fusarium* spp. colony forming units per gram of residual-container soil and potting soil before and after cleaning.

Nursery	Precleaning		Post-cleaning	Potting soil
	No storage	2-3 weeks storage		
FL	36,400	42,800	88,000*	0
GA	116,000	29,600	48,200	2,600
MS	43,800	72,800	14,200	0
NC	13,200	40,600	7,800	6,200

The nurseries that used a cleaning method had much lower *Fusarium* cfu/cavity than the FL nursery (Table 2). Among nurseries, there was no clear trend between the percentage of *Fusarium* spp. isolated from used container soil and the sampling dates (Table 3 through Table 6). The

most common *Fusarium* spp. isolated from container soils at the nurseries was *F. oxysporum,* followed by *F. proliferatum* and *F. solani.* A *Fusarium* spp., originally identified as *F. subglutinans* (Nelson and others 1983), was isolated from the residual soil of used containers from the FL, GA, and NC nurseries. This *Fusarium* spp. does not fit a more recent taxonomic key for the *Gibberella fujikuroi* species complex (Nirenberg and O'Donnell 1998) and remains unnamed. The only *Fusarium* spp. isolated from fresh potting soil was *F. proliferatum.*

In pathogenicity tests on 2-month-old longleaf pine seedlings, *F. oxysporum* and *F. proliferatum* from MS caused 20% and 10% mortality, respectively. No other isolates killed seedlings. The *F. proliferatum* isolates from the container soil at all four nurseries caused a larger canker response than the control (Table 7). The *F. proliferatum* isolates from MS caused a significantly greater cankering response in seedlings than those isolates of *F. proliferatum* from the GA and NC nurseries. The only other *Fusarium* sp. that caused a significant cankering response in

Table 2. Mean amount of soil collected and *Fusarium* colony forming units (cfu) per cavity following the cleaning method used on containers

Nursery	Precleaning		Post-cleaning	Potting soil
	No storage	2-3 weeks storage		
FL	36,400	42,800	88,000*	0
GA	116,000	29,600	48,200	2,600
MS	43,800	72,800	14,200	0
NC	13,200	40,600	7,800	6,200

*Average cavity size from 9 trays at 98.34 cm^2 and one tray at 147.51 cm^2.

Table 3. *Fusarium* species associated with soil remaining on containers after seedling removal at three different times and in fresh potting soil at Andrew's Nursery in Chiefland, FL

Species	No storage		Stored 2 weeks		Before sowing		Potting soil	
	%	number	%	number	%	number	%	number
F. oxysporum	60	24	73	29	77	31	0	0
F. solani	35	14	15	6	0	0	0	0
F. proliferatum	3	1	5	2	13	5	0	0
F. chlamydosporum	0	0	5	2	0	0	0	0
Fusarium species*	0	0	0	0	10	4	0	0

*Identified and confirmed as *Fusarium subglutinans* in 1997; does not fit a recent key for *Gibberella fujikuroi* species complex (Nirenberg and O'Donnell 1998).

Table 4. *Fusarium* species associated with soil remaining on containers before and after cleaning and in fresh potting soil at the T. W. Earle Nursery in Statesboro, GA

Species	Precleaning				Post-cleaning		Potting soil	
	No storage		Stored 3 weeks					
	%	number	%	number	%	number	%	number
F. oxysporum	55	22	73	29	65	26	0	0
F. proliferatum	8	3	20	8	18	7	100	0
Fusarium species*	15	6	0	0	10	4	0	0
F. solani	0	0	0	0	2	1	0	0
F. equiseti	5	2	0	0	0	0	0	0
F. avenaceum	5	2	0	0	0	0	0	0
F. chlamydosporum	3	1	3	1	0	0	0	0

*Identified and confirmed as *Fusarium subglutinans* in 1997; does not fit a recent key for *Gibberella fujikuroi* species complex (Nirenberg and O'Donnell 1998).

Table 5. *Fusarium* species associated with soil remaining on containers before and after cleaning and in fresh potting soil at the W. W. Ashe Nursery near Brooklyn, MS

Species	Precleaning				Post-cleaning		Potting soil	
	No storage		Stored 3 weeks					
	%	number	%	number	%	number	%	number
F. oxysporum	40	16	83	33	60	24	0	0
F. proliferatum	45	18	13	5	10	4	0	0
F. solani	8	3	2	1	30	12	0	0
F. avenaceum	5	2	0	0	0	0	0	0
F. lateritium	2	1	0	0	0	0	0	0

Table 6. *Fusarium* species associated with soil remaining on containers before and after cleaning and in potting soil at the Claridge Nursery, Goldsboro, NC

Species	Precleaning				Post-cleaning		Potting soil	
	No storage		Stored 3 weeks					
	%	number	%	number	%	number	%	number
F. oxysporum	34	13	73	29	18	5	0	0
F. proliferatum	47	18	3	1	74	20	100	19
F. solani	11	4	20	8	4	1	0	0
Fusarium species*	3	1	0	0	0	0	0	0

*Identified and confirmed as *Fusarium subglutinans* in 1997; does not fit arecent key for *Gibberella fujikuroi* species complex (Nirenberg and O'Donnell 1998).

Table 7. Average length of cankers on 8-month-old longleaf pine seedlings 6 months after inoculation with *Fusarium* spp. from container soil (C) following cleaning and fresh potting soil (P)

Nursery	Soil type	Inoculation	Mean canker length (mm) +		Confirmed re-isolation (%)
-	-	*Control*	0.1	a	-
FL	C	*F. oxysporum*	1.3	ab	20‡
FL	C	*F. proliferatum*	4.5	cde	100
FL	C	*Fusarium* species*	0.9	a	100
GA	C	*F. oxysporum*	1.9	a	86‡
GA	C	*F. proliferatum*	3.5	bcd	100
GA	P	*F. proliferatum*	0.6	a	100
GA	C	*Fusarium* species*	0.9	a	100
GA	C	*F. solani*	2.5	abcd	100
MS	C	*F. oxysporum*	5.7	de	86§
MS	C	*F .proliferatum*	7.1	e	100
MS	C	*F. solani*	0.9	a	60¶
NC	C	*F. oxysporum*	1.1	ab	100
NC	C	*F. proliferatum*	4.4	cd	100
NC	P	*F. proliferatum*	1.4	ab	100
NC	C	*F. solani*	0.9	abc	50‡

*Identified and confirmed as *Fusarium subglutinans* in 1997; does not fit new key for *Gibberella fujikuroi* species complex (Nirenberg and O'Donnell 1998).
+Data followed by the same letter do not differ significantly (alpha = 0.05) according to Tukey's Studentized Range (HSD) test.
‡*F. proliferatum* isolated.
§*F. solani* isolated.
¶*Penicillium* sp. contamination.

seedlings was the *F. oxysporum* isolates from the MS nursery. In pathogenicity tests using germinating seedlings, *F. proliferatum* from MS caused damping-off of all seedlings. No other *Fusarium* sp. caused damping-off from the three nurseries that were tested.

Discussion

Fusarium spp. were found to be regularly associated with the residual soil of used longleaf pine containers before and after cleaning. These results are similar to studies conducted in the West that found treating containers with bleach did not eliminate Fusarium from the containers (James and others 1988, Sturrock and Dennis 1988). Other studies that tested methyl bromide, hot water (James and others 1988) and steam (James and Gilligan 1988) for cleaning containers also failed to eliminate *Fusarium* spp. The only treatment documented as eliminating *Fusarium* spp. from containers was a 3 minute dip in 80 °C to 100 °C water (Sturrock and Dennis 1988). Currently, many container operations in the Northwest use a hot water treatment to sanitize used containers (per comm. Robert James, Forest Service, Coeur d'Alene, ID).

All cleaning methods tested resulted in less *Fusarium* cfu/cavity than the untreated containers from FL. Physically removing soil appeared to be as important as chemical sterilization for reducing *Fusarium* cfu/cavity. The 10% concentration of bleach did seem to reduce the number of Fusarium cfu/g of soil, whereas the 5% concentration did not. However, the 5% bleach treatment had much less residual soil than the 10% bleach treatment resulting in lower *Fusarium* cfu/cavity.

Fusarium proliferatum was the only species isolated from the unused potting soil at the GA and NC nurseries. In general, the species most isolated from the container soil of all four nurseries was *F. oxysporum*, which is consistent with other surveys of soil fungi from used containers (James and Gilligan, 1988, James and others 1988). Unlike these surveys, *F. proliferatum* and *F. solani* were the second and third most common species overall, except at the GA nursery, where an unnamed *Fusarium* spp. was more common.

The variability of the *Fusarium* isolates in causing seeding disease and mortality in the pathogenicity tests is similar to the findings of other scientists (Huang and Kuhlman 1990, James and others 1989, Tint 1945). *Fusarium proliferatum* from the MS nursery was the only isolate that may have been a threat to the next-year's container crop. The other *F. proliferatum* isolates from used containers produced only a weak-canker forming response, while the isolates from unused potting soil were nonpathogenic. Although the *F. oxysporum* isolate from MS did cause 20% mortality in the 2-month-old seedlings, it was not considered a significant threat to seedling production because the mortality was associated with wounding and there was no damping-off response in germinating seedlings.

Sanitation is a cornerstone of any integrated pest management program (Tinus and McDonald 1979), and most nurseries attempt to sanitize their containers to reduce all microorganisms (Dumroese and others 1990, James and Gilligan 1988, Sturrock and Dennis 1988). The ability of Andrew's Nursery to operate without cleaning used containers may be due to the possibility that pathogenic fungi are not present. Another possibility is that beneficial microorganisms have

been maintained in the residual soil of containers, which displaces or are antagonistic to potential pathogenic fungi. Regardless, the results of the pathogenicity testing of the FL isolates suggest that Andrew's Nursery apparently has no need at this time to clean used containers.

This evaluation was intended as an initial investigation of fungi associated with used containers before and after cleaning. Further studies would be required to determine if cleaning treatments are significantly different in reducing fungi and whether the reduction in fungi decreases disease development in container seedlings.

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A Comparison of Bareroot and Containerized Seedling Production

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Keywords

Bareroot nursery, container nursery, soil, media, pesticide use

Most nursery managers and culturists are comfortable growing bareroot seedlings. A few have become comfortable growing containerized seedlings. This discussion will compare the two systems, with a focus on SYP production, and will include a discussion on capital, equipment, space, and personnel requirements.

To briefly sum up the differences between bareroot and container nursery systems:

- Infinite possibilities are expected and usually obtained in bareroot nursery beds.
- Finite possibilities are planned and sometimes achieved in containers.

Space Requirements

Space utilization varies greatly between the two nursery systems. Based on a production rate of 30 MM seedlings, the difference between the systems is large.

	30 MM Bareroot	30 MM Container
Total Site	140 acres	50 acres
Irrigated Acres	72 acres	19 acres
Production Acres	45 acres	19 acres
Production	680,000/acre	1,579,000/acre
Production/site	214,000/acre	600,000/acre

Capital Requirements

Capital requirements also differ widely between bareroot and container nurseries, with each system having both advantages and disadvantages.

Bareroot system

- Requirements are soil-site specific.
- Significant land is needed for production.
- Substantial cold storage is needed following lifting.
- Standard agricultural equipment can be used for production.

Container system

- Requirements are not soil-site specific.
- Minimal land is needed for production.
- Minimal cold storage is required.
- Substantial specialized equipment is needed for production.

Cost comparison

30 MM Production Nursery ($/1000 Seedlings)

Bareroot		Container	
Land	$3 to 6	Land	$2 to 4
Buildings	$8 to 16	Buildings	$4 to 8
Materials	$3 to 6	Materials	$30 to 60
Equipment	$6 to 12	Equipment	$4 to 8

Personnel

Traditionally bareroot nurseries are managed by foresters with a strong farming background.

Horticulturists are more suited to growing containerized seedlings.

Equipment Requirements

Bareroot production relies heavily on standard farming equipment and implements.

Containerized production can take advantage of either abundant labor or sophisticated and specialized equipment.

Seedling Production

Growing

Sowing a bareroot crop usually requires less precision and less labor. Sowing can occur 10 to 20 times faster with just a few people.

Container growing begins with precise and accurate sowing at a relatively slow pace, usually requiring a number of people.

Bareroot Soils

- Infinite possibilities of soil types exist in bareroot nursery situations.
- Continuous management of bareroot nursery soil is needed for good production.
- Bareroot soils are always changing.
- Bareroot soils should contain 1% to 3% OM at a minimum for production.

Container Soils

- Finite possibilities exist for container media mixes.
- Nurseries usually rely on a formulated media.
- Container media is usually very uniform.
- Container media is sometimes 100% OM.

Fertilization

Bareroot

- Bareroot seedling fertilization usually involves the application of standard granular fertilizer.
- Liquid nitrogen is sometimes used in bareroot situations.

Container

- Controlled release (time-release) fertilizers are often used in container nurseries.
- Water soluble formulations can also be applied to the containers.
- Chemigation is often used in container nurseries as either a supplemental fertilization or for the entire nutritional needs of the crop.

Pest Management

Pest management is an important component of both bareroot and container nursery systems. There are similarities and differences in how pesticides are used and what types are required.

Activity	Bareroot	Container
Fumigation	Crucial	Not required
Insecticides	Same	Same
Herbicides	Same	Same
Fungicides	Same	Specialized

Lift, Pack, and Ship

Bareroot seedlings

- Fair weather is required for the operation.
- High volume production is standard.
- Lifting, packing, and shipping seedlings requires expensive equipment and is labor intensive.
- Generally packing materials are inexpensive.
- Storage and transportation are expensive

Container seedlings

- Fair weather is preferred, but not necessary for lifting.
- Equipment can be expensive, and lifting and packing is labor intensive.
- Production volume is possible, but expensive.
- Packing materials are generally expensive.
- Storage can be less expensive, but freight is more expensive than for bareroot seedlings.

The following cost comparison for lifting, shipping, and packing is based on a 30 MM production nursery with a 10 person crew:

Bareroot seedlings	Container seedlings
Average daily production is 300,000 to 800,000	Average daily production is 90,000 to 110,000
Seedlings are handled in multiples	Seedlings are handled individually
480,000 truck load	200,000 truck load
PRICE: $25 to 75/M	PRICE: $100 to 225/M

Conclusions

Successful container seedling production requires every detail of attention required by bareroot seedlings...They are just different details.

OPERATIONAL ROOTED CUTTINGS IN SOUTHERN PINES

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Abstract

Use of rooted cuttings for planting of pine trees has become increasingly popular. Vegetative propagation can deliver planting stock of higher genetic quality, increasing productivity and shortening rotations. Clonal forestry can also provide stands of higher uniformity, which can reduce logging and processing cost and yield a much more uniform product. One of the largest disadvantages of rooted cuttings is keeping the cost low compared to bareroot nursery stock. Several large companies in the southeastern United States are in the initial stages of developing operational rooted cutting programs.

Key Words

Container nursery, loblolly pine, slash pine, transplants

There has been a worldwide increase in the use of rooted cuttings for planting of pine trees. Several pines are vegetatively propagated on operational levels in the following areas:

New Zealand—*Pinus radiata*

Southern Australia—*Pinus radiata*

Northern Australia—*Pinus caribaea* x *elliottii*

Chile—*Pinus radiata*, *Pinus taeda*

Brazil—*Pinus taeda*

Venezuela—*Pinus caribaea*

South Africa—*Pinus patula*, *Pinus caribaea* x *elliottii*

Productivity is increased, rotations are shortened, and consistent genetic quality can be attained by using rooted cuttings. Logging and processing costs can be reduced and much more uniform stands and products will be produced.

A typical cutting is 3 to 4 inches (8 to 10 cm) long and has a basal diameter of around 1/8 inch (3 mm). It may be from a dormant or actively growing shoot. In the latter case, collection of the cutting may be delayed to allow some lignification of the shoot to make the cuttings more able to withstand rooting environments that are less than fully protected. Once the cutting is set, callus tissue is evident in 2 to 3 weeks and the emergence of adventitious roots from the basal region of the stem occurs within 5 to 6 weeks. Pine cuttings can be rooted in a field nursery, shadehouse, or greenhouse. Rooting directly in a field nursery bed has the advantages of reducing propagation costs (less labor-intensive handling of the rooted cuttings) and requiring no specialized structures for rooting. However, extreme variation in outdoor environmental conditions can result in a variable product and, in some cases, even loss of an entire crop. While a shadehouse does provide a more consistent rooting environment, in many climates one is prevented from utilizing the dormant winter cuttings because of low ambient temperatures. However, these dormant cuttings would not easily fit in with an operational program as they would be ready for outplanting in the summer. The rooting environment inside a greenhouse is the most controlled and has the additional advantage that 2 or 3 crops could be produced each year. However, the cost of the more specialized structure does increase production costs. In addition, containers and rooting substrate must be purchased for both the shadehouse and greenhouse rooting systems, and the added cost of handling containerized planting stock during tree planting needs to be considered. A containerized system in either a shadehouse or

greenhouse will yield a higher percentage of acceptable cuttings over a system where cuttings are stuck directly into nursery beds. QFRI in Australia has moved totally to shadehouse systems. They have a 20% higher rate of acceptable cuttings with the shadehouses over sticking cuttings in nursery beds. There is considerable cost in collecting and sticking cuttings as it is all done manually at this time. The goal is to maximize the number of acceptable cuttings that can go to the field for reforestation. One possible solution is a transplant production system where the cuttings are rooted in small plugs inside a greenhouse or shadehouse and then transplanted to a conventional forest tree seedling nursery. The greenhouse provides optimal and uniform rooting conditions, and allows one to expand the time of year cuttings are set. Small plugs allow the grower to maximize expensive greenhouse space. Certain types of small plugs might be amenable to transplanting to a bareroot nursery to allow the rooted cutting to finish growing like a bareroot seedling. This system will be particularly attractive if a machine can be found or made to transplant the cuttings. The rooted cuttings can then be handled like its seedling counterpart, and the logistics of handling millions of containerized plants in large scale reforestation operations could be avoided.

Producing root-cutting planting stock for forestry presents some problems not found with vegetative propagation for horticultural applications. Reforestation stock is a high-volume, low-cost product. Over 1.2 billion seedlings of loblolly pine (*Pinus taeda* L.) and slash pine (*P. elliottii* var. *elliottii* Engelm.) are produced in the United States each year at a cost of only a few cents per seedling. Most vegetatively propagated horticultural crops are produced as cultivars. A superior genotype is identified and then multiplied. This is a more difficult process for forest trees. One reason is that fairly extensive field-testing is required to identify the best trees to use for cloning. Another is that for most coniferous species, including the southern pines, donor plant maturation begins early and reduces propagation efficiency of the identified clones. This has led to 2 scenarios for pine rooted-cutting propagation and deployment.

In both scenarios, donor plants arise from controlled-pollinated crosses between genetically proven superior parents (a full-sib family). The first scenario involves a mass propagation of the entire family. This has the advantage of eliminating the field-testing requirement because the genetic values of the parents are already known from previous tests. It also minimizes the donor plant maturation problem because donor plants can be used for a short time and then new seeds can be germinated to replace them. This full-sib multiplication scenario, however, has the disadvantage that the genetic quality of the reforestation stock is only moderately improved relative to open-pollinated seedlings and falls far short of the quality that can be obtained with the second scenario, clonal forestry. Clonal forestry is analogous to the cultivar system in horticulture. A donor plant maturation problem can be approached in several ways. First, seedlings are rigorously pruned to produce "hedges" or "stool plants" that produce large numbers of cuttings and remain juvenile, at least for a few years. Hedging alone, however, may not be sufficient to retain seedlings at a juvenile stage for an adequate period of time. Two techniques are currently being evaluated that, hopefully, will maintain the juvenile, easy-to-root, phase of the hedge plants: 1) continuous hedging and serial rooting where the most vigorous rooted cuttings in a clonal line replace the older donor hedges; and 2) serial micropropagation or somatic embryogenesis accompanied by cryopreservation of tissue cultures.

Rooted cuttings are increasingly becoming a viable option for increasing the genetic quality of forest planting stock in high wood-cost areas and on the most productive sites. Several large companies in the southeastern United States are in the initial stages of developing operational rooted cutting programs. As more expertise and technical knowledge is gained about growing rooted cuttings, we become more efficient and the price of cuttings should drop. This has occurred in bareroot nurseries. When the cost of seedlings from 40 to 60 years ago are put into today's dollars, we are presently paying much less for seedlings than we did in the past.

STRATEGIC PLANS FOR THE HARDWOOD TREE IMPROVEMENT AND REGENERATION CENTER

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Key Words

Hardwood research, molecular genetics, genetic engineering, seed orchards

The mission of the Hardwood Tree Improvement and Regeneration Center (HTIRC) at Purdue University is to advance the science of hardwood tree improvement and genomics in the central hardwood region of the United States by:

- Developing and disseminating knowledge on improving the genetic quality of hardwood tree species,
- Conserving fine hardwood germplasm,
- Developing elite hardwood trees for restoration and regeneration of sustainable hardwood forests and riparian zones for production of forest products and maintenance of genetically diverse ecosystems, and
- Developing recognized and respected science leaders in hardwood forest genetics.

The HTIRC is a regional collaborative research, development, and technology transfer effort. The partnership includes the USDA Forest Service North-Central Research Station, National Tree Seed Laboratory, and Northeastern Area State and Private Forestry; Purdue University Department of Forestry and Natural Resources; Indiana Department of Natural Resources Division of Forestry; Indiana Hardwood Lumbermen's Association; Walnut Council; and the Fred M. vanEck Trust. The HTIRC is unique in several aspects:

- It has a regional focus on states comprising the central hardwood region,
- It is a true partnership of federal, state, university, industry, landowner groups, and private individuals who contribute financial support and advice, and
- It will generate basic knowledge and applied technologies in hardwood tree genomics, improvement, and regeneration for tree nurseries, industry, agencies, and landowners.

The HTIRC is located at Purdue University because of its role in the Midwest as a recognized center for agricultural genomics research. It is housed in the Whistler Hall of Agricultural Research with biotechnology and genomics faculty and 6 departments in the school of agriculture. This co-location of genetics faculty is intended to stimulate cross-fertilization of research ideas and multidisciplinary research. In addition, because of the high standards of achievement and international recognition of its faculty, high-quality undergraduate and graduate students will be drawn to the various programs represented in Whistler Hall.

The idea for HTIRC was conceived in 1998 because of a perceived void in hardwood tree improvement research in the central hardwood region of the Midwest and Northeast. The birth of HTIRC occurred at the same time that the region was experiencing a severe production shortage of hardwood seedlings, which was estimated to be anywhere from 25 to 50 million trees annually, and production was expected to continue to decrease 20% annually. In addition, the majority of seedlings being produced in state nurseries

were of an unknown genetic source because nurseries rely upon seed collectors to collect and transport seeds to the point of purchase at the nursery. Thus, the majority of seedlings being produced are unimproved, of unknown fitness for sustainable forestry, and of unknown genetic diversity.

The hardwood industry was also concerned about the future quantity and quality of the resource for its lumber and manufacturing sectors. Due to political and social pressures, federal forests have significantly reduced the volume of hardwood timber that is being harvested annually. Small private woodlots that supply a significant amount of hardwood timber are not being managed in a sustainable manner, ownership is not continuous over numerous rotations to ensure sound forest management, and many woodlots are being converted to residential and recreational uses. In addition, the diameter of timber harvested today continues to be smaller than what it has been due to shorter rotations. Last, the hardwood industry was concerned that it was not taking advantage of new biotechnologies that could increase wood production through tree improvement activities that improve wood quality, growth, and pest resistance.

The professional forester community was also concerned about loss of genetic quality in remaining hardwood woodlots and natural forests. They felt that trees that are currently being managed for future timber harvest do not have the same desirable traits for straightness and vigor and that past forest harvest practices of continually taking the "best" trees may have resulted in loss of genetic quality of remaining germplasm. The international economic, social, and political environments also influence the demand for hardwoods. Human population growth continues to expand rapidly, and consumer demand for quality hardwood, at some point, will outstrip the region's ability to produce it unless consumers are willing to accept substitute materials. Much of the United States and European demand for hardwood lumber is currently met within the United State's northern and central hardwood zones, and hardwood production has not shifted to developing countries in any significant manner. The time may come when this pattern of production for world markets can no longer be maintained because of decreased supply and the environmental consequences of heavy timber extraction on natural environments.

In the central hardwood region, water quality has been degraded by agricultural intrusion along waterways, and flooding has further degraded these riparian zones that include major rivers and their tributaries. A significant effort is being made to restore hardwood trees and other native vegetation in these riparian zones. For the most part, unimproved trees are being used, and knowledge of how to restore these degraded areas is lacking, which has resulted in the failure of many plantings. The opportunity exists for this significant portion of the land base to be a future site for quality hardwood regeneration, although political forces will influence that reality.

Funding for many conservation plantings comes from the Conservation Reserve Program (CRP), Conservation Reserve Enhancement Program (CREP), and Wetland Reserve Program (WRP). These programs currently account for the majority of hardwood tree planting, and they are increasingly focused on improvement of water quality and wildlife habitat. The genetic characteristics of the trees being planted are unknown, and the potential exists for genetic failures as these plantings reach maturity.

Many consumers have not differentiated between the role of plantation forests and natural forests. They readily accept that agronomic crops are grown for the purpose of food production and consumption rather than for regeneration of annual vegetation. However, consumers have similar aesthetic and spiritual values that they hold for trees whether they are in an urban, plantation, or natural forest environment. If this does not change, plantations may not be accepted as the alternative method for growing highly productive crop trees that would allow the country to maintain natural forests as preserves for biodiversity and recreation. These attitudes exist despite the fact that it would take only a marginal set aside of land currently in forestland cover to produce all of the wood necessary to meet human demands for wood consumption.

Central and northern hardwoods are more desirable than southern hardwoods because of slow, more even growth and the supply of European hardwoods is limited. Because of this, the HTIRC will hold unique importance with the Central United States to develop superior

hardwood trees for markets that supply developed nations. There are no other hardwood tree improvement research centers in the world and few individual hardwood research programs that have a mandate to satisfy a regional clientele and are financially supported to undertake a long-term program in tree improvement.

HTIRC will be unique because of Purdue University's relationship with Donald Danforth Plant Science Center in St. Louis, MO. The Danforth Center is a partnership of the Missouri Botanical Garden, Monsanto, Purdue University, University of Missouri-Columbia, University of Illinois, and Washington University in St. Louis. Its mission is to increase understanding of basic plant biology and apply new knowledge to sustain productivity in agriculture and forestry. HTIRC should benefit from its access to world-class plant scientists and its ability to collaborate in the graduate education of its students.

HTIRC will be virtually integrated with molecular and classical genetics, tree physiologists, silviculturists, and nursery and regeneration specialists. Its strength will be its ability to perform basic, applied, and developmental research so the basic genetic knowledge that is created will be delivered to industry and private landowners in value-added products rather than knowledge that only benefits the scientific community.

HTIRC will not be the single or sole institution performing hardwood research desired by the hardwood industry, nursery operators, government agencies, forest landowners, and the general public. The region has many outstanding scientists who perform valuable basic and applied research on various species, and it will be essential that the whole hardwood scientific community remains viable to meet these research needs. In addition, HTIRC itself will not employ pathologists, entomologists, biochemists, enzymologists, economists and all of the other scientific disciplines that will be necessary for research collaborations to provide scientific data for evaluation of the ecological and environmental fitness of HTIRC products. Productive working relationships with scientists from other institutions are necessary for the success of the center.

Strategic Directions

HTIRC has 6 strategic directions:

1. Improve the genetic quality and regeneration of fine hardwoods, including black walnut, black cherry, and northern red oak, through application of classical breeding, genomics, molecular markers, genetic modification, advanced propagation, seed production, technologies and silviculture.
2. Establish a highly credible hardwood genetics research center that will be recognized as a leader in forest genetics and thereby become a leading graduate education and training facility for future scientific leaders in hardwood forest genetics.
3. Hire and nurture pre-eminent scientists who will build the credibility of the research program and be highly competitive for federal research grants.
4. Establish the Martell Experimental Forest and Conference Center as a significant site for education and training of consulting foresters, nursery practitioners, and landowners in nursery management and hardwood culture.
5. Communicate, convey, and market the work of HTIRC in order to be perceived as the pre-eminent international center for hardwood genomics and biotechnology.
6. Secure funding for an endowment to ensure long-term organizational stability, provide for operating support of the research program, and establish funded research positions with the center.

Objectives

The following are objectives for implementing the strategic directions:

- Develop research and technology transfer programs that provide knowledge for management and maintenance of sustainable, genetically diverse natural forests and highly productive domesticated trees for plantation hardwood crops that provide an array of products.
- For black walnut, black cherry, and northern red oak: develop genetic maps, molecular markers, tissue culture and genetic engineering technologies, advanced seed orchard and seed handling technologies, breeding orchards, and

experimental nurseries for the production of elite families and cultivars, identification of superior seed trees, and assessment of genetic quality and diversity in natural stands.

- Assess the need and develop a regional hardwood breeding and seed orchard cooperative for central hardwood seed zones as desired by state tree improvement cooperators.
- Take leadership in documentation of hardwood research discoveries and dispersal of knowledge by hosting scientific conferences, symposia, workshops, and field days and publish books, proceedings, and brochures that convey this knowledge to a wide array of end users.
- Provide for annual evaluation and other periodic review of HTIRC programs to ensure that the mission and vision remain focused and relevant.

Accomplishments to Date

In the initial year since establishment, staff at the HTIRC have developed tissue culture systems for northern red oak and black walnut, developed over 300 black walnut molecular markers for use in genetic mapping and marker-assisted breeding, established new breeding orchards for black cherry and black walnut, and established a field planting for screening Midwest-adapted blight-resistant American chestnut.

TRENDS IN NURSERY RESEARCH AND PRODUCTION

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Abstract

Forest nursery production is at an all-time high in the southern United States, and to maintain and increase this production capacity we need to integrate research and operational technology. We must improve the technology to increase production of container southern pine seedlings, especially for longleaf pine. Bareroot nursery managers have challenges to maintain the current level of nursery productivity and to increase the production of hardwoods for wetland restoration and nontraditional species such as wire grass for longleaf pine restoration. Finding alternatives for methyl bromide causes uncertainty in the operation of many bareroot nurseries where the loss of this chemical may cause significant disease and weed problems.

Key Words

Seed treatments, seed predation, pesticides, longleaf pine, tree planting

The United States economy depends on the South for 67% of its pulpwood, 50% of its plywood, 40% of its hardwood lumber, and 33% of its softwood lumber (USDA Forest Service 1997). Timber is the highest valued crop in the region, representing an annual economic value of $90 billion. As harvests from public lands in the Pacific Northwest have been reduced, greater pressure is placed on southern forests to make up this deficit. The South can expect an increase in demand for pulpwood, lumber, and other products. Most of these pressures will fall on private lands, which make up nearly 90% of the forests in the South. It is apparent that the South faces unprecedented timber production pressures, especially on private lands.

As the pressure to increase nursery capacity in the South continues, our capability to conduct research to support nurseries is declining. Within the USDA Forest Service, there has been a significant loss of technical expertise in reforestation, particularly in nursery research (Barnett and Tinus 1999). Research capability in the universities, too, is limited. This means that we face challenges in being able to provide the research needed to address some of our nursery-related problems.

RESEARCH ENHANCEMENTS FOR NURSERY OPERATIONS

To sustain the productivity of our southern forests, new or enhanced bareroot and container nursery technology is needed. The rapidly increasing demand for longleaf pine planting stock has exceeded our capability to produce enough high-quality seeds to meet current needs for nursery production. Longleaf pine seeds are the most difficult of the southern pines to produce. Special effort is required to obtain quality seeds, and the technology and guidelines to produce such seeds are lacking (Barnett and McGilvray 2000). Comprehensive guidelines are needed to provide the knowledge needed by seed dealers, nursery managers, and silviculturists so that high-quality seeds can be produced in quantities that meet current needs.

A significant problem with longleaf seeds is poor seed germinability. Until the knowledge is available to produce high-quality seeds consistently, we need technology to upgrade seedlots with low viability by removing seeds that will not germinate. There is potential to separate good from bad seeds by use of chemometrics (Meglen 1988). This approach uses near far-red spectra scanning technology to sort seeds quickly

based on chemical properties that are related to seed viability. A cooperative effort is underway to apply this technology to longleaf pine seeds. If successful, this approach will be developed and used with other southern pine seeds.

Although direct seeding is currently not widely used for regenerating southern pines, there is interest by small landowners in technology to reforest their land inexpensively. In addition, seeding is an approach to regenerate large acreages quickly after wildfires or other catastrophes. In order to apply direct seeding successfully, chemical coatings are needed to protect seeds from birds and rodents. The fungicide thiram is an effective bird repellent and is labeled for this purpose (Derr and Mann 1971). Endrin, the rodent repellent in the coating, is no longer manufactured in the United States. Efforts have been underway for a number of years to find a replacement. Recent evaluations show that capsicum (hot sauce) significantly reduces rodent predation (Barnett 1998). The combination of capsicum and thiram offers an option to protect seeds for those interested in using direct seeding (Nolte and Barnett 2000).

Container production is now the preferred method of growing longleaf pine planting stock because seedling establishment is improved by use of container-grown seedlings. However, growers typically lose 10% to 20% of these seedlings during production due to disease problems. Longleaf pine seeds are hosts to a number of pathogenic fungi (Pawuk 1978). Recent studies show that eliminating these fungi from the seeds by sterilants such as hydrogen peroxide or fungicides such as benomyl significantly increases the percentages of plantable seedlings from a seedlot (Barnett and others 1999). Application of fungicides during the nursery-growing period also reduces mortality due to disease, but the greatest gain can be made by controlling the microorganisms on the seedcoats.

Another important research effort is to find an effective replacement for methyl bromide in bareroot nurseries. Although a few chemicals have seemed promising, they have not been as effective as methyl bromide for controlling disease and weed problems in nurseries (Lemons 1999). Other non-chemical approaches such as steam sterilization of the soil and application of compost material and mulches are even less effective at the present time (Carey 1999). Obviously, there is a critical need for continued research to find an effective replacement for methyl bromide in nurseries.

Issues Related to Nursery Production

There are a number of issues related to projecting future needs of nursery stock across the South. First, will the demand for container longleaf pine seedlings continue? Much of the demand for longleaf pine stock is related to incentive programs that give an added bonus for planting longleaf seedlings. No one knows for sure if these programs will be maintained beyond the current funding period, but a tremendous interest in the restoration of the longleaf pine ecosystem will likely keep a strong nursery program for this species.

Some foresters anticipate that interest in container production of loblolly and slash pine will significantly increase because planting container seedlings results in increased survival and early growth. Managers with interest in shortening rotations may accept this technique on highly productive lands. If so, container production of these species could replace any loss due to a reduction in incentive programs for longleaf pine.

It is difficult to anticipate the demand for bareroot nursery stock. During the last few years, although there has been an increase in nursery production across the South, the demand for seedlings has generally exceeded production. Some may consider this deficit a short-term effect; however, it may hold over the long term. In many States across the South, harvests of forests now exceed growth. There are, then, numerous efforts underway to provide incentives to landowners to reforest their lands. For example, the Louisiana legislature passed a Forestry Productivity Act to fund incentive programs to help landowners regenerate forest lands (Barnett 1999). Initiatives are underway or planned in other States. Such efforts, and the short-rotation program of forest industry, assure a continuing demand for plantable nursery stock.

There is also an increasing demand for nursery production of hardwood species, primarily for wetlands restoration. It is likely that the need for such species will increase. A number of organizations and conservation groups, such as

Ducks Unlimited and the U.S. Fish and Wildlife Service (Aycock 1999), are supporting reforestation and restoration efforts. Thus, the demand for hardwood nursery stock will continue or may even increase significantly.

The Kyoto conference on controlling greenhouse gases has opened a discussion of carbon credits. Carbon credits provide the right to generate a certain level of carbon dioxide if compensating steps were taken to reduce CO_2 by another activity (Karrfalt and Lantz 1999). Some of these credits would bring new players into reforestation, such as power utilities, who would pay for tree planting on private land.

A new aspect of nursery production is to grow non-traditional species such as wire grass that is used for longleaf pine ecosystem restoration in the Southeast. As emphasis on restoration of longleaf, wetland hardwood species, and other species like bald cypress increases, there will be a need for forest nursery capacity dedicated to such efforts.

Conclusions

There are a number of opportunities for research to enhance nursery operations. Problems remain in the production and successful planting of longleaf pine seedlings. Guidelines can be made available to simplify the production of quality longleaf pine seeds and seedlings. An important need is methodology to sort viable from nonviable seeds. Research is underway to determine if such separation is feasible. In container longleaf seedling production, new presowing seed and seedling applications may reduce pathogenic fungi problems that significantly reduce the numbers of plantable seedlings. Another major problem is finding an effective replacement for methyl bromide. Therefore, continued nursery-related research may accomplish many potential gains.

The demand for forest nursery production should not decline significantly in the near future. In fact, it is likely that the need for both container and bareroot nursery stock will be stable or even continue to increase. Driving forces that contribute to this demand include: 1) short-rotation and high-intensity forest practices; 2) demands for forest products that currently exceed growth in southern pine forests; 3) Southern States' incentive programs that encourage landowners to reforest their land; 4) increasing demands for hardwood species in restoring wetlands; 5) broad regional interest by small landowners and conservation groups to restore the longleaf pine ecosystem; and 6) a growing need for nurseries to grow nontraditional species such as grasses and shrubs for a multitude of uses.

There are many challenges ahead for researchers and nursery managers. Not only will the quantity of production continue to be stable or even to increase, but new technologies will be needed to produce difficult-to-grow species. The challenge is to provide research to overcome problems and to apply technology to increase operational production.

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Comparison of Tillage Equipment for Improving Soil Conditions and Root Health in Bareroot Nurseries

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Abstract

Two series of trials were conducted in northern bareroot forest nurseries to determine: 1) the effects of different incorporation implements and two chemical application rates on the efficacy of dazomet fumigation; and 2) soil penetration resistance in the vertical soil profile following sub-soiling by two different implements. When target pests were located > 18 cm deep, the spading machine was more effective than three different rotary tillers in reducing fungi. Mortality and disease ratings in this trial were lowest and percentages of shippable seedlings highest for the spading machine at the end of the 3+0 year. However, when target pests were < 18 cm deep, all of the implements performed equally well at the lower dazomet rate. Cone indices obtained through the vertical soil profile one year after treatment for an alternative subsoiler were much lower (in other words, decreased penetration resistance) than those obtained for the cooperating nursery's subsoiler. Importance of understanding what planned tillage events in a nursery will and will not accomplish is discussed.

Key Words

Fumigation, dazomet, soil management, subsoiling

Tillage operations are part of overall soil management practices associated with the culture of bareroot forest nursery seedlings. The impact of such operations on the physical and biological properties of soil can vary according to the tillage tool used. Among the physical properties affected by tillage implement use are soil structure, water drainage through the soil profile, resistance of soil to root penetration, field topography, and subsoil conditions. Tillage events associated with incorporation of green manure or other amendments (for example, peat) affect such physical properties as soil texture, soil fertility, organic carbon, and pH. In addition, incorporation treatments impact biological properties of the soil. For example, incorporated crop residue provides substrate for potential buildup of soil-borne microorganisms. At the same time, improved soil tilth, organic carbon, fertility, and reduced mechanical resistance may result from incorporation of crop residue and are beneficial for seedling growth. Finally, when tillage implements are used for incorporation of certain pesticides (for example, granular formulations) the biocidal activity of the product occurs mainly within the zone of incorporation.

In this paper the results of studies we have undertaken to examine the use of various tillage implements and their impact on seedling production, root health, soil biota, and other soil properties are summarized. In one series of trials we determined the effects of different incorporation implements and 2 chemical application rates on the efficacy of dazomet (a granular soil fumigant) on selected soil fungi and the seedling crop produced in the treated fields. Preliminary results are also presented on a second series of trials designed to evaluate subsoiler use on resistance of soil to penetration.

DAZOMET INCORPORATION TRIALS

Materials and Methods

Field trials were conducted in a Wisconsin and a Michigan nursery to compare the effectiveness of 2 application rates of dazomet when incorporated by different implements. Three types of rotary tillers (Fobro Kulti-Pak Rotary Tiller®, Kuhn Rotary Tiller®, and Northwest Tiller®) and 1 spading machine (Gramegna®) were compared in the Wisconsin nursery where the soil is a Vilas loamy sand. The Fobro tiller, the Gramegna spading machine, and a tandem, double-gang disk cultivator (John Deere Disc Cultivator®) were compared in the Michigan nursery where the soil is also a loamy sand. Details of the tillage tool lengths and operational working width for each implement are found in Table 1.

The dazomet was applied at the appropriate test rate (250 and 500 lbs/ac = 285 and 570 kg/ha, respectively) with a drop spreader to the trial fields (0.7 ha for each rate in Wisconsin; 0.8 ha for each rate in Michigan). The fields were then divided equally to accommodate the 4 (Wisconsin) or 3 (Michigan) incorporation implements. In the Wisconsin trial, each implement was operated at speeds recommended by growers experienced with the specific implement (Table 1), while a common speed (2 mph) was used for all implements in the Michigan trial. Following incorporation, a roller was used to compact the soil surface (top 4 cm), and irrigation was applied per the chemical manufacturer's recommendations (Pennington 1995). White pine was seeded in the trial fields in early October of the fumigation year in each location. Sowing rate in each nursery was based on seedlot germination assay results and the nursery's desired stand density.

Biocidal efficacy of dazomet was determined for all implement X dazomet application rate combinations using lettuce seed germination tests and selected fungal bioassays. For the lettuce assay, soil samples were collected immediately before fumigation and again after dazomet incorporation but prior to water activation. The bioassay was conducted per standard procedures (Morton Chemical Co., Chicago, Illinois) with water added just prior to jar sealing to activate the dazomet. Soil samples for the fungal assays were collected the day before chemical incorporation, at 4 weeks, and at 11 months after incorporation. Standard assay procedures (see Juzwik and others (1998) for *Fusarium* and Juzwik and others (1988) for *Cylindrocladium*) were then conducted with these samples.

The actual concentrations and depths of dazomet in the field soils following incorporation were estimated based on surface application rate and operational depth for each implement (= actual dazomet incorporation rate). At the end of the 3+0 year, seedling production (quantity and quality) in each location was determined.

RESULTS

Biocidal activity in soil

On presence or absence of assay organisms. At both nurseries, lettuce seed germination results more closely mirrored the operational depth of each implement tested than the results of fungal bioassays, regardless of dazomet application rate. Seeds generally failed to germinate within the 14-day assay period for soils collected from within the operational depth range for each implement (see Table 2 for Wisconsin results; Michigan results not shown). Recovery of *Fusarium* spp. and *Cylindrocladium* spp. propagules at different depths differed by dazomet application rate, implement, and assessment date. In the Wisconsin study, poor to fair control of *Fusarium* spp. and *Cylindrocladium* spp. was achieved in the low dazomet application areas. In the high dazomet application areas, good to excellent control of these fungi was found for the Fobro and the Gramegna spading machine in the upper 30 cm (Table 2). In the Michigan nursery, all implements performed equally well regardless of dazomet application rate, based on *Fusarium* spp. presence/absence after treatment (data not shown). However, *Fusarium* spp. presence was much less frequent before treatment in the Michigan nursery than in the Wisconsin nursery, especially at the lower depths.

On numbers of soil-borne fungi. Effect of the biocide on the actual numbers of fungal propagules in the treated soils differed by implement and soil depth. The Gramegna spading machine was superior to the other implements at the high dazomet rate in reducing *Fusarium* spp. levels in the Wisconsin nursery when all depths were taken into account (Figure 1B), and also at depths > 12 cm in the low dazomet application areas (Figure 1A). Results for *Cylindrocladium* spp. reduction were similar to those

Table 1. Specifications of tillage implements and their operation in dazomet field trials at Michigan and Wisconsin nurseries

Ground speed *(mph)*	Manufacturer and model *	Tillage tool	Working width *(cm)*	Nursery where used
0.7	Kuhn EL80N	42 tines of 22-cm length mounted on 7 flanges; tine offset angle of 110°	178	Wisconsin
0.7 2.0	Fobro Kultipak 1700	60 blades of 22-cm length mounted on 17 flanges; tine offset angle of 151°	170	Wisconsin Michigan
1.8	Northwest Tiller DHC-96-SC	48 tines of 27-cm length mounted on 8 flanges; tine offset angle of 95°	239	Wisconsin
0.7 2.0	Gramegna Spading machine V84/30B	6 spades of 13-cm width by 18-cm length	137	Wisconsin Michigan
2.0	John Deer Disc Cultivator	28 concave disks (44-cm diameter with 5-cm cup) in tandem, double-gang configuration; front disk set serrated	305	Michigan

*Kuhn, Fobro, and Northwest rotary tillers all have vertical action, forward rotation with L-shaped tines; Gramegna spading machine is a crankshaft type-digging machine.

for *Fusarium* spp. (data not shown). In the Michigan nursery, propagules of *Fusarium* spp. were reduced to/or near zero in the top 12 cm of soil regardless of dazomet rate and implement used (data not shown). Below 12 cm, propagule numbers were quite low both before and after treatment.

Seedling production

Seedling mortality. Seedling mortality was determined at the end of the first and third growing seasons at both nurseries. Percentage of dead seedlings within established subplots varied by sampling date, dazomet application rate, and implement in the Wisconsin nursery. Seedling mortality was lower in the high dazomet rate (< 1% to 4%) plots in the Wisconsin nursery than in the low-rate plots (1% to 7%). Within the high dazomet rate plots at this nursery, mortality at the end of the third growing season was lowest in the Gramegna spading machine plots compared to the mortality in the other implement plots. In the Michigan nursery, seedling mortality was < 1% for all implements and both dazomet application rates combined, regardless of sampling date.

Root disease severity. Average root disease ratings varied by sampling date, dazomet rate, and implement in the Wisconsin nursery and by sampling date only in the Michigan nursery. Average root disease rating, on a scale of 1 (healthy) to 5 (all root rotted or root collar lesion present), was low (< 1.3) on the first sampling date in both nurseries for both dazomet application rates and all implements. On the second sampling date (in other words, mid-October of the 3+0 year), differences in disease

Table 2. Biocidal efficacy of a high rate of dazomet incorporated into Wisconsin nursery soil by four tillage implements *

Soil depth	Lettuce seed germination				*Fusarium* spp. presence				*Cylindrocladium* spp. presence			
	Fo	Ku	NW	Gr	Fo	Ku	NW	Gr	Fo	Ku	NW	Gr
0-6		--	--	--		-+	-+	-+		--	--	--
6-12		--	--	--		-+	++	--		--	--	--
12-18	-+	--	--	--	-+	++	++	--	-+	--	++	--
18-24	++	++	-+	--	-+	++	++	-+	-+	++	++	--
24-30	++	++	++	-+	-+	++	++	-+	-+	++	++	-+

*Implements: Fo = Fobro KutiPak rotary tiller; Ku = Kuhn rotary tiller; NW = Northwest rotary tiller; Gr = Gramegna spading machine. Actual dazomet incorporation rates: 0.41 kg/m^3; 0.26 kg/m^3; 0.21 kg/m^3. Results of two replicates reported. For lettuce bioassay, "-" represents no germination and "+" represents germination for soil samples collected immediately after incorporation. For fungal assays, "+" represents presence and "-" represents absence or below detectable levels for soil samples collected 4 weeks after incorporation.

ratings were apparent in both locations. In the Wisconsin nursery, average disease ratings were lowest for the Gramegna spading machine at both the low rate (Gramegna = 1.7 versus other implements = 2.1 to 2.4) and the high rate (Gramegna = 1.2 versus other implements = 1.5 to 2.0). At the end of the 3+0 year in the Michigan nursery, lower root disease ratings were found for the Gramegna spading machine and the Fobro tiller (< 1.2) compared to those in the John Deere disk plots (1.8) for both rates combined.

Shippable seedlings. Percentages of live seedlings that met nursery specifications for shipping were similar for both the low and high dazomet application rates of the Michigan nursery (Figure 2). The most apparent differences were found in the Wisconsin nursery where percentages of shippable seedlings differed by implement (Figure 2), particularly in the high rate plots where higher percentages (> 80%) of shippable seedlings were found for the Fobro and Gramegna spading machine plots than for the other 2 implements (63% to 73%). We speculate that the lower percentages of shippables at the higher dazomet rate for the Kuhn and NW Tiller were due to sublethal effects of residual dazomet granules in the upper 15 cm of soil that were not activated until the first growing season.

Conclusions of Incorporation Studies

Major findings of the biocidal assays were as follows: 1) in the upper 12 cm of soil, all implements and dazomet application rates worked satisfactorily to reduce fungi and prevent lettuce seed germination for both nurseries; and 2) at depths > 18 cm in the Wisconsin nursery, the Gramegna spading machine was more effective than the other implements in reducing fungi and in preventing lettuce seed germination. Furthermore, the high dazomet rate in the Wisconsin nursery was more effective than the low rate for the Gramegna spading machine.

Major findings arising from the seedling assessments were: 1) mortality and disease ratings

Figure 1

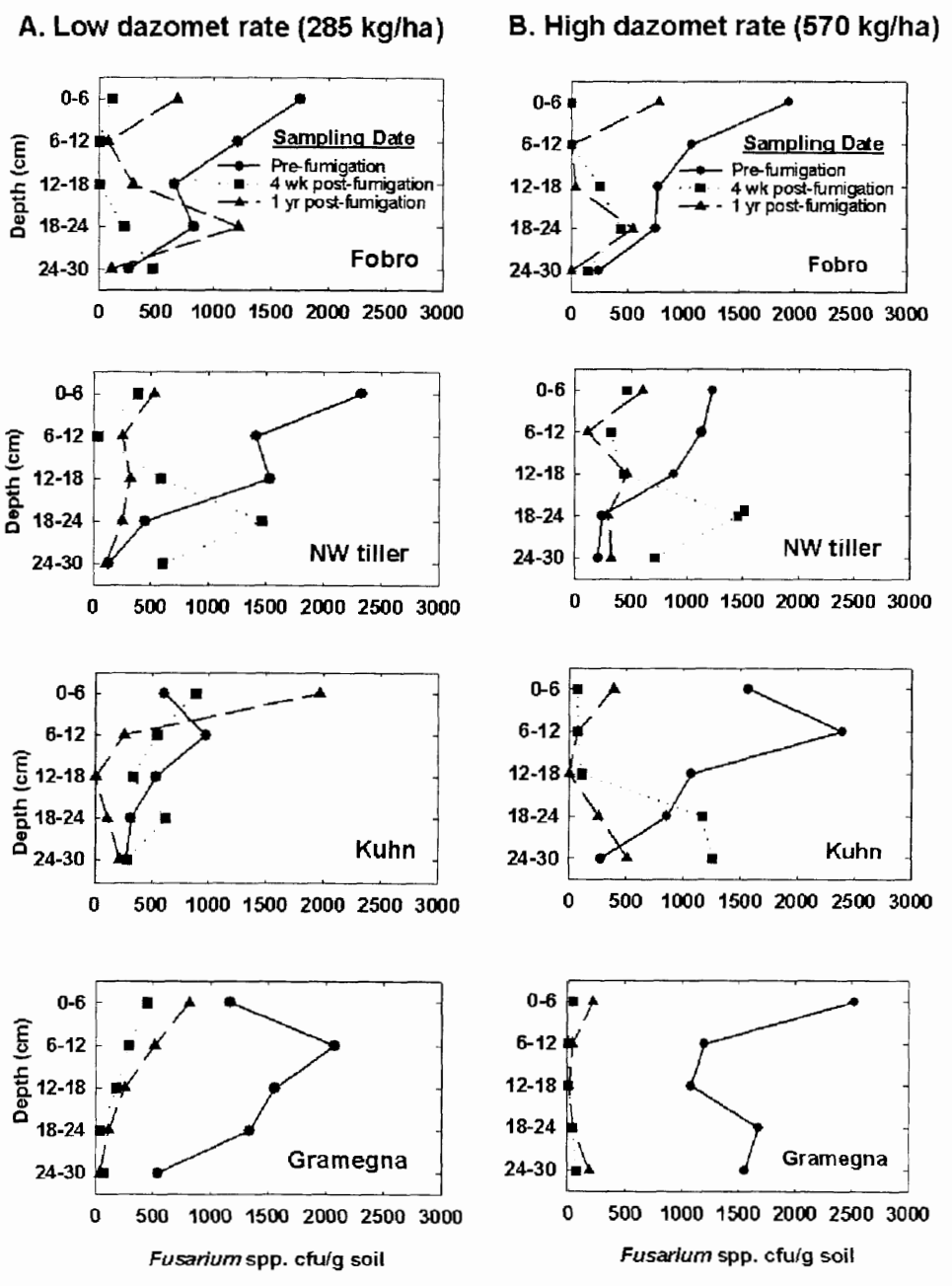


Figure 1. Efficacy of two rates of dazomet incorporated by different implements in reducing Fusarium *spp. Populations in the vertical profile of soils in the Wisconsin nursery trial: A) low (285 kg/ha), and B) high chemical rate (570 kg/ha).*

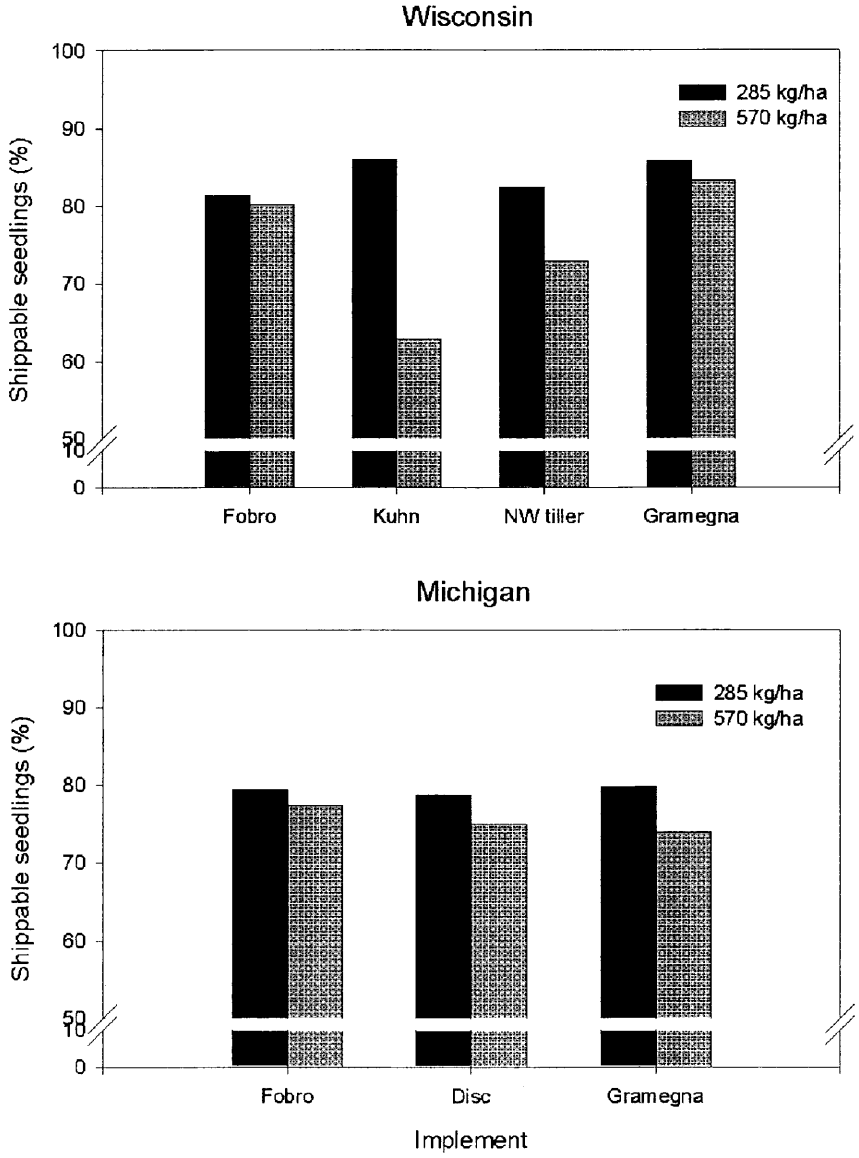


Figure 2. Percentage of shippable white pine seedlings grown in dazomet rate and tillage implement efficacy trials in Michigan and Wisconsin nurseries.

were higher in the Wisconsin nursery than in the Michigan nursery; 2) after 3 growing seasons in the Wisconsin nursery, lower seedling mortality and disease ratings were found in the areas receiving the high chemical rate compared to the low application rate for 3 of 4 implements tested; and 3) mortality and disease ratings in the Wisconsin nursery were lowest and percentages of shippable seedlings were highest for the Gramegna spading machine at the end of the 3+0 year.

SUB-SOILING TRIAL

Materials and Methods

Two subsoiling implements and their method of use were compared in a Minnesota nursery in 1998.

Alternative subsoiler. The shanks of the alternative equipment tested (DMI, Inc., Goodfield, IL) can be adjusted for hortizontal and vertical placement. The 2 parabolic steel shanks (61 cm long) were equipped with winged tips (18 cm wide), and the

shanks were slightly offset on the toolbar and placed 46 cm apart. The operating depths of the shanks were determined based on cone indices recorded through the soil profile using a soil penetrometer (Rimik, Canberra, Australia) in preliminary assessments. Cone indices reflect the force (in MPa) required to steadily insert the penetrometer's cone through the soil profile. Values were recorded every 1.5 cm from the surface to a 45-cm depth. This subsoiler was only operated within demarcated seedbed areas in order to prevent tractor tire compaction immediately following subsoiling. One pass of the alternative field seedbeds was made with the subsoiler shanks set at a 14-cm depth, and a second pass was then made in the reverse direction with the 2 shanks set for penetration to 36 cm.

Control subsoiler. On the nursery's subsoiler, 3 fixed parabolic shanks (58 cm long) are 46 cm apart. This implement was used at its maximum operating depth, approximately 54 cm. Seedbeds of the control field were not demarcated until late September, just prior to seeding but 6 weeks after subsoiling (standard practice for the nursery). One pass was made across the control field (15 m by 165 m) in elongated, over-lapping loops per the nursery's standard practice. During this operation, the tractor driver places tractor tires in previously made tire paths when shifting across the field. The tractor paths used during subsoiling, however, do not necessarily line up with the paths established during demarcation of seedbeds in late September. Thus, it is possible that new "hard-pans" are formed under the earlier tractor paths that had been used in these areas.

Assessment. Resistances of the soils in the study fields to penetration were determined 1 week before and 13 months after subsoiling. Numerous insertions were made with a portable cone penetrometer to a 45-cm depth in the control and alternative fields. Cone indices were then plotted against soil depth to compare treatments.

Results and Preliminary Conclusions

The 2 study fields differed in their patterns of penetration resistance prior to subsoiling treatments. Prior to subsoiling in the field where the alternative implement was used, cone indices increased gradually with soil depth (Figure 3A). This pattern is consistent with results obtained in other fields where a disk has been used to incorporate cover crops (see Juzwik and others 1998). In this particular field, a disk had been used 2 weeks prior to the pre-treatment assessment to incorporate cover crop residue. In the field where the control implement was used, the observed pretreatment cone indices (Figure 3A) are consistent with fields where moldboard plows have recently been used (see Juzwik and others 1998). In fact, a moldboard plow had been used 2 weeks prior to the pretreatment resistance assessment to incorporate cover crop residue in this particular field.

The resistance profiles following treatment also differed for the 2 fields, but these differences were attributed to the subsoiling implement used in each. The alternative subsoiler resulted in low cone indices in the soil profile to 30 cm, while cone indices in the control field began to increase markedly around 16 cm where average values ranged from 3 to 4 MPa (Figure 3B). Cone indices of > 2.75 MPa are considered limiting to plant root penetration in light textured soils (Labowski and others 1998). Thus, the use of the alternative subsoiler resulted in more favorable soil resistance conditions for the rooting zone (zero to 25 cm) of the subsequent woody crop than did the nursery's (in other words, control) subsoiler. We believe several aspects of the alternative subsoiler (for example, horizontal and vertical placement of shanks, the winged tip of the shanks, the way it was used in the field) contributed to the implement's superior effectiveness.

Concluding Remarks

Existing field conditions and prior tillage operations should be considered when determining incorporation/injection depth and rate of any fumigant selected for preplant, soil fumigation. In our dazomet studies, biocidal activity and seedling production were related to both incorporation depth and rate of dazomet (both surface application rate and actual incorporated rate). Thus, it is important for nursery staff to consider the depth distribution (in other words, < 18 cm versus > 18 cm) of the target pests when selecting the incorporation implement for dazomet. In addition, the dazomet application rate should be adjusted for increased

Figure 3

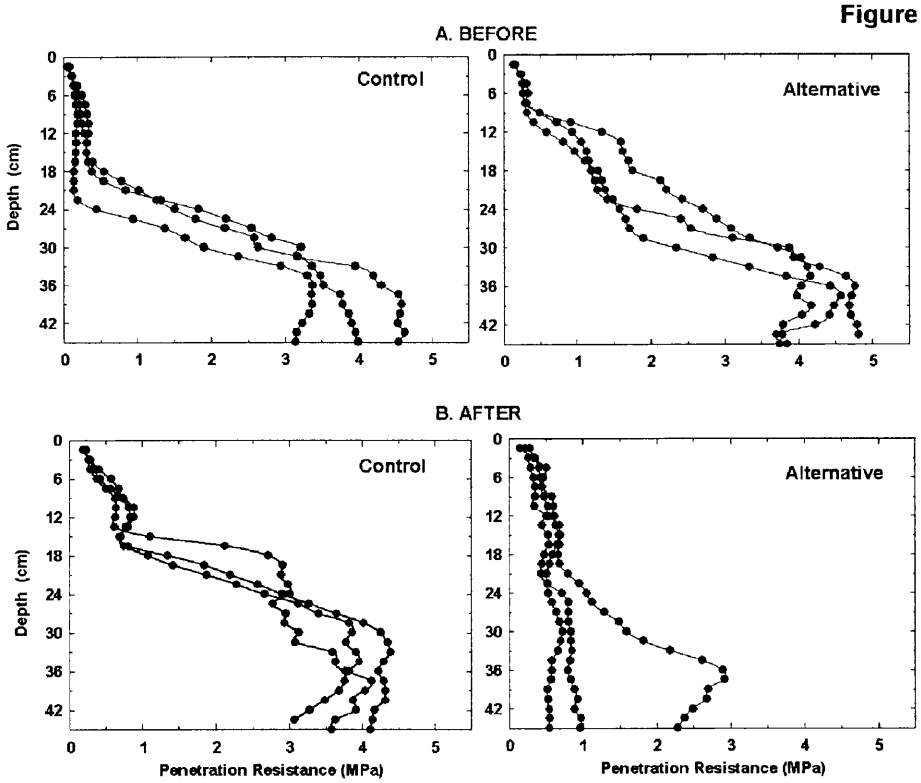


Figure 3. Penetration resistance (MPa) measured before and after subsoiling treatments in a Minnesota nursery. Each graph contains results of three penetrometer insertions in one of four sampling locations in the particular study field.

soil volume when the product is incorporated to greater depths. Shallower incorporation of the product can be expected when the ground speed of the tractor equipped with an implement increases, based on the authors' results of a related study. Likewise, the pattern a tractor driver follows in subsoiling across a field is as important as the selection of the subsoiling tool itself in ameliorating compacted soil conditions. In conclusion, whether selecting implements for incorporating dazomet or conducting subsoiling in fields between woody crop cycles, it is wise for nursery staff to question whether their planned tillage operation will actually accomplish the outcome they would like to see.

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SLOW-RELEASE FERTILIZERS IN BAREROOT NURSERIES

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Abstract

Maintaining sufficient soil fertility in tree nurseries for good tree growth can be implemented by annually performing soil analyses and following a fertility maintenance program. Percentage recovery by trees of fertilizer applied indicates efficiency of fertilizer use. There is a wide variation in the recovery among the various fertilizer elements. Our research has shown that, of the primary nutrients, nitrogen recovery is much more variable, spanning from deficits to almost complete recovery. Low efficiency of nitrogen recovery is the usual rather than the exceptional occurrence. Soil characteristics, climatic conditions, cultural practices, fertilizer source, and fertilizer application method influence nutrient recovery. Most applied nitrogen is either recovered rather soon after application or lost from the soil-plant system. An approach to resolving the problem associated with nitrogen mobility and environmental protection has resulted in the development, testing, and use of several controlled-release or slow-release fertilizers. Slow-release fertilizers have not been widely used in bare root tree seedling nurseries and Christmas tree production. The lack of research in this area causes growers to sometimes guess at fertilizer applications, which can result in economic losses and environmental degradation. Several kinds of slow-release fertilizers are being manufactured and used in the turf industry rather successfully.

Polyon-coated slow-release fertilizer trials were introduced in the state bare root nursery in spring 1999. The feasibility of slow-release efficient fertilizer use and prevention of groundwater contamination was compared with conventional fertilizer use. Monitoring input of nutrient added as fertilizers and losses of nutrient in leachates indicated lower losses in slow-release fertilizer beds compared to conventional fertilizer beds. However, the uptake of nitrogen and morphological characteristics of 1+0 white pine seedlings were similar in the conventional and the Polyon-coated slow-release fertilizer plots.

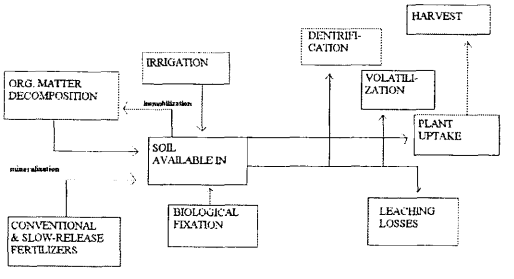
The goal of a soil fertility program is to maintain nutrient levels that will optimally suit the needs of the seedlings. We have confirmed that slow-release fertilizers added in lower amounts can yield trees comparable to those obtained with conventional fertilizer and can provide better ground-water protection.

Key Words

Nitrogen balance, cation balance, anion balance, nicronutrients, leachate, groundwater contamination

Slow-release fertilizers have not found wide application in tree seedling nurseries and Christmas tree production. The lack of research in this area causes growers to sometimes guess at fertilizer applications, which can result in economic losses and environmental degradation. Over-fertilization wastes growers' input dollars, and may contaminate the groundwater, while under-fertilization produces poor-quality seedlings and trees.

The efficiency of fertilizer use is measured in terms of percentage recovery of that applied. Nitrogen recovery is very variable and frequently tree crops do not recover the nitrogen from the applied fertilizer. Direct loss of N occurs from application in excess of seedling needs, or application at the wrong time, wrong place, or wrong material. Indirect N losses are caused by leaching, erosion, volatilization, denitrification and, to a lesser extent, fixation. Figure 1 illustrates the sources of input and output (losses) of nitrogen that can occur.



NITROGEN BALANCE IN SOIL

Figure 1.

Slow Release Study

Since the mid 1950s, a number of slow- or controlled-release products have been introduced as fertilizers. However, not much success was achieved with slow-release fertilizers in bare root tree nurseries. Over the years, several slow-release products with various types of coating materials have been available as fertilizers and successfully used in the turf industry as well as in the production of container-grown plants.

Slow-release fertilizers are relatively more expensive per unit than inorganic, conventional fertilizers, but there are a number of advantages due to their release rate. Slow-release fertilizers can be applied at the time of seeding or planting, which in turn, can supply the needed nutrients for a full growing season, thus eliminating additional fertilizer application and saving on labor; this offsets the increased cost of slow-release fertilizers. Use of slow-release fertilizers can reduce the loss of soluble materials through leaching and runoff and minimize contamination of the environment.

Experimental Trial

In spring 1999, slow-release fertilizer trials were established in raised 1+0 white pine beds at the Wilson State Nursery, Boscobel, WI. Slow-release fertilizers were applied to a coarse sandy soil of a quartzitic river terrace. Fertilizers used included a conventional fertilizer (15.5-0-0) calcium nitrate; Polyon, polymer-coated, slow-release fertilizer (12-0-42) potassium nitrate; Polyon, polymer-coated, slow-release fertilizer (19-6-12) N+P+K mix, ammonium nitrate + ammonium phosphate + calcium phosphate + potassium sulfate. Two replicate rows of each of the three fertilizers were set up. Conventional fertilizer was added at the rate of 182 lb/acre and slow-release fertilizer at the rate of 42 lb/acre of actual N over the growing season.

Two porous-cup samplers were installed before fertilization in each row at the 1-m depth. Water leachate samples were collected every week over the entire spring, summer, and late fall.

Seedlings were collected at the end of the growing season for analysis of morphological and chemical characteristics. The morphological characteristics included height, diameter, and oven-dry weight of seedlings. The chemical characteristics included nutrient concentration of major and micronutrients in roots, stems, and needles. Average nutrient uptake per seedling was calculated based on the average oven-dry weight per seedling.

Results and Discussion

First Growing Season

The morphological characteristics of 1+0 white pine did not show very great differences between slow-release and conventional fertilizer in seedling weight and height. Seedling weight ranged from 0.268 to 0.280 g in the slow-release fertilizer rows versus 0.290 g in the conventional fertilizer rows. Height ranged from 6.05 to 6.10 cm in slow-release fertilizer rows versus 6.11 cm in conventional fertilizer rows. Diameter of seedlings

in slow-release fertilizer rows ranged from 1.75 to 2.33 mm versus 2.60 mm in the conventional fertilizer rows. Results show that the diameters of seedlings were slightly higher in the conventional fertilizer rows for the first growing season (Table 1).

Table 1. Effect of conventional and slow-release fertilizer on the morphological characteristics of 1+0 white pine.

Treatment	Seedling Weight (g)	Height (cm)	Diameter (mm)
Conventional			
Calcium nitrate			
15.5-0-0	0.290	6.11	2.60
Slow-release, Polymer-coated			
Potassium nitrate			
12-0-42	0.287	6.05	1.75
N+P+K mix			
19-6-12	0.268	6.10	2.33

The nutrient uptake of macronutrients by seedlings did not vary greatly between treatments. However, some nutrients did reflect the fertilizer source used; for example, calcium was highest at 1.50 mg Ca/seedling in the conventional fertilizer (calcium nitrate) treated rows versus 1.22 mg Ca/seedling in the slow-release (potassium nitrate) and 1.29 mg Ca/seedling in the slow-release (N+P+K mix). Potassium was highest at 2.35 mg K/seedling in the slow-release (potassium nitrate) versus 2.21 mg K/seedling in conventional fertilizer rows and 1.80 mg K/seedling in slow-release (N+P+K mix) fertilizer rows (Table 2). There were no conspicuous differences between the three fertilizer treatments in the uptake µg/seedling of micronutrients (Table 3).

Nitrate-N in Leachate of Treated Rows

The leachate analyses for nitrates showed that, in spring, initially the nitrate in all three treatments ranged from 55.8 to 66.2 ppm. In early summer, an increase in nitrate-N was observed in all three treatments, ranging from 87.5 to 187.2 ppm.

Table 2. Nutrient uptake by and concentration in 1+0 white pine seedlings grown in beds treated with conventional and slow-release fertilizers.

Treatment	N	P	K	Ca	Mg	S
			Uptake (mg/seedling)			
Conventional						
Calcium Nitrate						
15.5-0-0	5.05	0.87	2.21	1.50	0.75	0.58
Slow-release, Polymer-coated						
Potassium nitrate						
12-0-42	4.95	0.84	2.35	1.22	0.75	0.80
N+P+K mix						
19-6-12	4.84	0.81	1.80	1.29	0.77	0.51
			Concentration (%)			
Conventional						
Calcium nitrate						
15.5-0-0	1.74	0.30	0.76	0.52	0.26	0.20
Slow-release, Polymer-coated						
Potassium nitrate						
12-0-42	1.72	0.29	0.82	0.43	0.26	0.28
N+P+K mix						
19-6-12	1.81	0.30	0.67	0.48	0.29	0.19

Table 3. Micronutrient uptake by and concentration in 1+0 white pine seedlings grown in beds treated with conventional and slow-release fertilizers.

Treatment	B	Cu	Fe	Mn	Zn
		Uptake (µg/seedling)			
Conventional					
Calcium nitrate					
15.5-0-0	4.08	2.45	451	32	30
Slow-release, Polymer-coated					
Potassium nitrate					
12-0-42	4.07	2.24	439	32	29
N+P+K mix					
19-6-12	3.79	2.20	525	34	28
		Concentration (ppm)			
Conventional					
Calcium nitrate					
15.5-0-0	14	8.4	1555	110	103
Slow-release, Polymer-coated					
Potassium nitrate					
12-0-42	14	7.8	1530	111	101
N+P+K mix					
19-6-12	14	8.2	1958	127	104

Further increase in nitrate-N continued in all three treatments until early fall, and in November, the nitrate-N in leachates of all fertilized rows ranged from 106.7 to 253.6 ppm. Towards winter, the nitrate-N in leachates of all fertilized plots decreased, with drops ranging from 80.7 to 195.3 ppm. Throughout the growing season, the nitrate-N concentration in the leachates of conventional fertilizer rows was consistently higher than the leachates from slow-release fertilizer-treated rows (Table 4).

Figure 2 illustrates the nitrate-N concentration in the collected weekly leachate June through December. Highest amounts of nitrate-N concentration were observed during July and September in conventional fertilizer-treated rows followed by slow-release potassium nitrate, with slow-release N+P+K mix being the lowest of the three fertilizers. The nitrate-N concentration in the slow-release N+P+K mix leachates remained consistently lower than the leachate from the conventional (calcium nitrate) and slow-release potassium nitrate-treated rows throughout the growing season.

Mass Balance of Cations and Anions

Leaching of anions—nitrates (NO_3^-) and sulfates ($SO_4^=$)—always includes cations Ca, Mg, and K as well. In order to compare anions plus cations present in the leachate samples of the fertilizer-treated rows, the concentration of cations and anions in parts per million (ppm) were converted to meq/L (Table 5). Conventional fertilizer (15.5-0-0) calcium nitrate rows showed that, on average, 50% of the cations leached as nitrates and 30% as sulfates. Slow-release fertilizer rows of potassium nitrate (12-0-42) showed that, on the average, 30% of the cations leached as nitrates and 23% as sulfates. The slow-release fertilizer rows of N+P+K mix (19-6-12) showed that, on average,

Table 4. Nitrate-N in leachate from fertilizer-treated 1+0 white pine beds over the growing season.

Month	Conventional	Slow-release	
		12-0-42	19-6-12
	ppm	----------ppm--------	
June	66.2	55.8	59.4
July	187.2	91.4	87.5
August	270.4	171.1	116.5
September	265.9	182.3	135.8
October	271.8	193.5	180.5
November	253.6	143.7	106.7
December	195.3	119.2	80.7

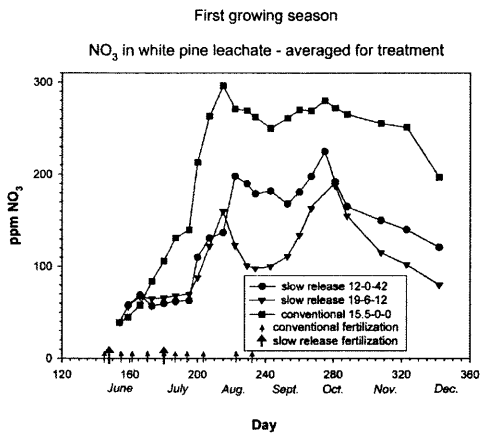


Figure 2.

32% of the cations leached as nitrates and 25% as sulfates. The slow-release N+P+K mix treated rows had the lowest amounts of cations (Ca, Mg, and K) and anions (nitrates and sulfates) in the leachates compared to the conventional fertilizer (calcium nitrate) and slow-release fertilizer (potassium nitrate) treated rows.

Second Growing Season

Conventional fertilizer (15.5-0-0) calcium nitrate; Polyon, polymer-coated, slow-release fertilizer (12-0-42) potassium nitrate; Polyon, polymer-coated, slow-release (19-6-12) N+P+K mix, ammonium nitrate + ammonium phosphate + calcium phosphate + potassium sulfate were applied at the same rate as the first growing season. The rates were 158 and 42 lb N/acre for conventional (15.5-0-0) and slow-release (12-0-42 and 19-6-12), respectively. The seedlings were collected from the fertilizer-treated rows in early summer to document any changes in seedling morphology and chemical content between the three fertilizer treatments.

The conventional (15.5-0-0) and slow-release (19-6-12) N+P+K mix showed similar heights of 19.15 and 19.2 cm and diameters of 2.63 and 3.03 mm, respectively. The seedlings in the slow-release (12-0-42) were smaller in height (17 cm); diameters of 2.6 mm were similar to the seedlings in the conventional fertilizer rows (Table 6).

The uptake of nutrients by seedlings (Table 7) on average indicated that the seedlings growing in conventional fertilizer (15.5-0-0) rows took up 10.68 mg N, 7.31 mg K, and 4.90 mg Ca, which

Table 6. Effect of conventional and slow-release fertilizers on the morphological characteristics of rising 2+0 white pine.

Treatment	Seedling O.D. weight (g)	Height (cm)	Diameter (mm)
Conventional			
Calcium nitrate			
15.5-0-0	0.92	19.15	2.63
Slow-release, Polymer-coated			
Potassium nitrate			
12-0-42	0.77	17.00	2.69
N+P+K mix			
19-6-12	0.86	19.20	3.03

was higher than the amounts taken up by seedlings growing in the slow-release potassium nitrate and N+P+K mix (19-6-12) treated rows. The seedlings growing in the slow release fertilizer (19-6-12) N+P+K mix showed a higher uptake of N, P, Ca, and Mg than the seedlings growing in the slow-release fertilizer (12-0-42) potassium nitrate rows. The slow-release N+P+K mix also had the highest amounts of P (1.87 mg P/seedling) compared to the seedlings grown in the slow-release (potassium nitrate; 1.49 mg P/seedling) and conventional (1.31 mg P/seedling).

In general, the micronutrient uptake by seedlings growing in the conventional fertilizer rows was lower than the seedlings growing in the slow-release fertilizer (potassium nitrate) and N+P+K mix rows. However, uptake of micronutrients by seedlings growing in all three fertilizer treated rows was within the accepted range found for conifers (Table 8). Concentrations of nutrients in seedlings are also provided in Tables 7 and 8. Large amounts of approximately 158 to 180 lb/acre of actual N are added as conventional N fertilizers to conifers over the growing season. To reduce this amount, the feasibility of slow-release fertilizer trials were established on loamy sandy soil. Based on tissue analysis, seedling weight and density of 35 seedling/ft^2, about 15 lb/acre of nitrogen was taken up by 1+0 white pine at the end of the first growing season. Based on tissue analysis, seedling weight and density of 35 seedling/ft^2, during the early summer of the second growing season, the uptake of N varied

Table 5. Mass balance of cations, nitrates, and sulfates in leachates from conven-tional and slow-release fertilizer treated beds of 1+0 white pine.

Month	K+	Ca++	Mg++	Total Cations	NO3–	SO4=
		meq/L				
		Calcium Nitrate[1]				
June	0.006	1.95	2.97	4.91	1.07	1.24
July	0.055	3.63	3.08	6.50	3.02	1.77
August	0.263	3.08	4.79	8.11	4.36	2.57
September	0.245	2.90	4.89	8.00	4.29	2.56
October	0.235	2.94	4.96	7.49	4.38	2.38
November	0.297	2.92	4.14	7.34	4.09	2.06
December	0.176	2.50	3.21	6.89	3.15	1.85
		Potassium Nitrate (12-0-42)[2]				
June	0.007	2.93	2.63	5.57	0.899	1.18
July	0.089	3.04	3.33	7.32	1.47	1.83
August	0.252	3.30	5.53	9.05	2.86	1.89
September	0.240	3.16	5.40	8.78	2.94	1.91
October	0.218	3.21	5.12	8.53	3.12	1.80
November	0.184	2.55	4.65	7.36	2.32	1.76
December	0.134	2.01	3.28	7.63	1.92	1.46
		N+P+K Mix (19-6-12)[2]				
June	0.001	2.48	2.90	5.37	0.957	0.88
July	0.083	3.27	2.48	6.24	1.41	2.11
August	0.269	2.93	3.27	6.46	1.88	1.90
September	0.246	2.58	3.28	6.09	2.19	1.37
October	0.224	2.39	3.36	5.96	2.91	1.13
November	0.179	2.38	2.53	5.09	1.72	1.16
December	0.149	1.87	1.80	5.57	1.30	1.22

[1] Conventional fertilizers
[2] Slow-release fertilizers

Table 7. Nutrient uptake by and concentration in rising 2+0 white pine seedlings grown in beds treated with conventional and slow-release fertilizers.

Treatment	N	P	K	Ca	Mg	S
		Uptake (mg/seedling)				
Conventional						
Calcium nitrate						
15.5-0-0	10.68	1.31	7.31	4.90	2.10	1.41
Slow-release, Polymer-coated						
Potassium nitrate						
12-0-42	4.41	1.49	5.11	3.23	1.82	1.53
N+P+K mix						
19-6-12	7.75	1.87	5.24	3.81	2.10	1.53
		Concentration (%)				
Conventional						
Calcium nitrate						
15.5-0-0	1.16	0.14	0.79	0.44	0.23	0.15
Slow-release, Polymer-coated						
Potassium nitrate						
12-0-42	0.57	0.19	0.66	0.42	0.24	0.20
N+P+K mix						
19-6-12	0.90	0.22	0.61	0.44	0.24	0.18

Table 8. Micronutrient uptake by and concentration in rising 2+0 white pine seedlings grown in beds treated with conventional and slow-release fertilizers.

Treatment	B	Cu	Fe	Mn	Zn
		Uptake (µg/seedling)			
Conventional					
Calcium nitrate 15.5-0-0	2.82	6.08	127	85	76
Slow-release, Polymer-coated					
Potassium nitrate 12-0-42	7.29	5.28	502	196	84
N+P+K mix 19-6-12	13.85	6.14	394	107	85
		Concentration (ppm)			
Conventional					
Calcium nitrate 15.5-0-0	3.1	6.6	1000	92	83
Slow-release, Polymer-coated					
Potassium nitrate 12-0-42	9.5	6.9	652	255	109
N+P+K mix 19-6-12	16	7.1	1000	124	99

between fertilizer treatments. The seedlings growing in conventional fertilizer rows took up the highest amount of nitrogen (34 lb N/acre), followed by slow-release N+P+K mix at 23.6 lb N/acre. The lowest amount of nitrogen was taken up by the seedlings growing in slow-release fertilizer (potassium nitrate) at 13.4 lb N/acre. The final amounts of nitrogen taken up by 2+0 white pine seedlings growing in the three fertilizer-treated rows will be determined at the end of the second growing season in August or September 2000.

Conclusions

1. Certain slow-release fertilizers appear to be promising for use in bare root conifer nurseries.
2. Slow-release fertilizers can be added in substantially lower amounts compared to the amounts added as conventional fertilizers.
3. Slow-release fertilizers are usually more expensive than conventional nitrogen fertilizers, but their use may be justified where fertilizer application is required at frequent intervals, especially in sandy textured soils.
4. Leaching of nitrates to groundwater is considerably reduced and nitrogen fertilizer can be cost-effectively used.
5. Results obtained to date clearly show considerable amounts of nitrate leaching in the conventional fertilizer rows versus the slow-release fertilizer rows.
6. Leaching of nitrates is always accompanied by leaching of cations (Ca, Mg, and P), which are also essential nutrients for seedlings.
7. Reducing annual application of fertilizer may contribute directly to overall energy savings, both in fertilizer energy and energy of application.
8. Based solely on the amounts added, the comparison of fertilizer cost clearly shows that slow-release fertilizer was $41 per acre cheaper than the conventional fertilizer. This did not take into account the cost of fuel, labor, number of applications, and compaction.
9. Slow-release N+P+K mix appears to be very suitable for use as a fertilizer source for white pine.

Seedlings appeared slightly paler in July in the slow-release rows. However, towards the end of August, seedlings greened up in the slow-release fertilizer rows and the differences between seedlings evened out visually between the slow-release and conventional fertilizer rows.

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Red Oak Propagation at the Griffith State Nursery, Wisconsin Rapids, Wisconsin

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Storandt, J. 2002. Red Oak Propagation at the Griffith State Nursery, Wisconsin Rapids, WI. In: Dumroese, R.K.; Riley, L.E.; Landis, T.D., technical coordinators. National Proceedings: Forest and Conservation Nursery Associations—1999, 2000, and 2001. Proceedings RMRS-P-24. Ogden, UT: USDA Forest Service, Rocky Mountain Research Station: 120-121. Available at: http://www.fcnanet.org/proceedings/2000/storandt.pdf

Key Words

Bareroot nursery, 1+0 seedling, 2+0 seedling

Production

Annual seedling goals at Griffith are approximately 1 million bareroot red oak seedlings. We sell both 1+0 and 2+0 seedlings. Red Oak has become a major species in our nurseries over the past 15 years. In 1986, statewide distribution of red oak was 325,000 (1% of state production). Of this, 76,000 were from Griffith. In 1999, red oak distribution hit 2.7 million (13% of total production). We have learned a lot in the past 15 years.

Current specifications for red oak at Griffith are as follows:

1+0: 6" top, 8" root, and 1/8" caliper

2+0: 10" top, 8" root and 3/16" caliper

Seed Procurement

Most of the northern red oak seed used at the Wisconsin State nurseries is purchased off the open market from the general public. In the fall of 1999, we paid $30 per bushel. The price was increased from $20 just this past year. We receive acorns at all three nurseries as well as at several satellite buying stations in various locations within the state. Most of the seed is hand picked, although some is now harvested with the Bag-O-Nut machines. We require only clean seed be delivered; no caps or other debris allowed. Our program has never tried storing red oak and depends on the current crop to reach seeding goals. Red oak collection time in Wisconsin runs from about September 15 to October 15. Once leaf drop occurs, most collection is over. If the seed crop is plentiful, we can usually reach our purchase goals of 1,500 Bu statewide. The recent increased interest in direct seeding has resulted in higher demand, and therefore higher prices, for the available seed.

Nursery Culturing

Soil Preparation

Fields selected for growing red oak generally have a pH of 5.5 to 6.0 and an organic matter content of 3% to 3.5%.

In August the fields are fumigated with Basamid at a rate of 350 lbs/acre. The fields are disked and leveled within two weeks after fumigation. One to two weeks prior to seeding, the areas receive 150 lbs of 18-46-0, which is rototilled in to a depth of about 5 inches. This is the final preparation and areas are now ready to seed.

Seeding

All seeding is done in the fall between September 20 and October 20. We seed at a rate of 4 quarts per 48 sq ft bed. This equals about 600 to 700 seeds per bed (4 ft x 12 ft). Final desired bed densities are approximately 400 shippable seedlings, or about 8 per square foot.

Up until the fall of 1999, all of our red oak was hand seeded. Last fall we purchased a five-row hardwood seeder from Whitefield and have been very pleased with its performance after the initial season. It is easy to calibrate and feeds smoothly.

In the fall, shortly after seeding, we apply Goal herbicide at 2.5 pints per acre. The beds are then covered with a thin layer of Hydro-mulch and

guarded with a 12 gauge for squirrel predation. We normally have good snow cover from late November through the end of March.

Culturing in Year One

Germination occurs between May 5 and May 18 on the average. Fertilization begins within two weeks of germination, with 4 to 5 applications of fertilizer applied at two-week intervals. We apply 34-0-0 at 150 lbs per acre each time, in other words, approximately 250 lbs of available N per growing season. The first two applications are blended with 100 lbs per acre of 0-0-50 because our soils are generally low in K.

No herbicides are used, with the possible exception of Fusilade for grass control if needed. Generally crown closure occurs within four weeks of germination and the shade suppresses weed growth. Row cultivators are used in the alley-ways.

Every 10 to 15 days, a mixture of Benlate and Bravo is applied to control leaf diseases such as anthracnose. We also apply Pounce insecticide every 10 to 15 days for aphid and leaf hopper control.

No root culturing is done in the 1+0 stage. We have found that it sets back growth too much. We may top prune in September if top growth exceeds 17".

Irrigation if needed, is 1.5 inch per week.

The growing season at Griffith averages 140 days.

Culturing in Year Two

Fertilizer is reduced to 3 to 4 applications of 34-0-0 at 100 lbs per acre, which equates to 100 to130 lbs of available N per year. No fungicide or insecticide during 2+0 year, and no chemical weed control is done at all during this year.

Roots are undercut at 7" to 8" right after the first flush occurs, which is early June. We use a stationary, very sharp V-blade mounted on wheels to undercut.

Irrigation occurs at a rate of 1.5" to 2" per week.

The 2+0 crop is top pruned at 16" to 17" in mid September and ready for spring lifting.

Rodent bait stations are scattered throughout both 1+0 and 2+0 oak fields throughout the growing season.

Summary

Key ingredients for growing quality red oak in central Wisconsin include:

- pH 5.0 to 6.0,
- OM 3% to 4%,
- Good soil drainage,
- Application of 200 to 300 lbs of available N,
- Starting with good quality seed,
- Insect and disease control,
- Undercut 2+0 crop to promote lateral root development.

Tree Planting Incentive Programs: How You Can Make These Programs Work for You

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Key Words

Tree planting, federal programs, state programs

If you are like most people, the thought of dealing with bureaucratic, slow-moving, cumbersome, government programs does not excite you. And the thought of incentive programs is boring at best. However, I would like to challenge you to try to gain enough of a comfort level with the federal tree planting incentive programs that you will be able to see them as opportunities for business growth, not impediments to the free market. These programs are opportunities for private business; I hope to get you thinking along the lines of "how can I use this to improve my business?"

I speak from experience when I say, don't try to figure out how to change the programs to make them easier, more efficient, or more intuitive. The politics of most programs would make your head spin; it is amazing to me that enough of the original intent remains to do some good. Better to learn how to work within the system and have it work for you, instead of fighting it. However, in order to do that you need some basic knowledge of how the individual programs work, which programs relate to tree planting, and which have the highest potential for future funding.

Other information I want to share this morning includes what I see as current and future opportunities for nurseries to use these programs to the mutual advantage of the business and the landowner. I see exciting potentials to combine private and public resources to accomplish more than either sector can do alone. For instance, the Private Forestry Study Team of 1999 reports that DNR foresters have only assisted 18% of the estimated 260,000 nonindustrial private (NIPF) landowners over a 10-year period. State nurseries do not and will not meet all this demand. But the real potential lies beyond merely growing trees. There is a whole realm of associated services that landowners who are planting trees could use and could be provided by private sources.

First, I would like to cover some of the general and then specific aspects of tree planting assistance programs before discussing the opportunities. You only need to know enough about each program to provide customer assistance and make estimates on future demands. Do not try to learn the administrative details; these questions are better handled by program administrators like FSA offices, NRCS personnel, and me.

There are many types of forestry incentive programs, but for tree planting the 2 important programs are the tax incentives, such as reforestation tax credit, which I will not cover, and reimbursement programs. There are both state and federally funded programs in Wisconsin. Rules for the federal programs are generally more rigid and are developed with relatively little input from the field. Our state program is easier to understand and use, but also has some restrictions from a political source that cannot be easily

changed. Within Wisconsin, we have statues, administrative rules, and budget restrictions that define the program parameters.

Within each program are unique features that may result in either restrictions or opportunities. For example, some programs have a limited selection of species from which to select. Other programs primarily focus on wetlands or grasslands and are of limited use in tree planting. Additionally, some programs may not be offered in all areas of the state. Some programs have more historical impact and may be the ones you wish to focus on. Finally, knowledge of these programs may inspire you to become more actively involved in the technical committees that develop standards and recommendations for these programs, or at least get on the mailing lists for updates and proposed revisions.

The range of programs you may have heard of include the following: the Conservation Reserve Program (CRP), the Conservation Reserve Enhancement Program (CREP), the Environmental Quality Incentive Program (EQIP), the Wetland Reserve Program (WRP), the Forestry Incentive Program (FIP), the Stewardship Incentive Program (SIP), and the Wisconsin Forest Landowner Grant Program (WFLGP). There are brochures available that briefly describe the programs.

CRP—This program requires landowners to offer bids through the Wisconsin Farm Services Agency for per-acre payments they will accept to keep their highly erodible or marginal croplands out of production. Contracts are awarded for 10 years (15 for hardwood plantings). In exchange, landowners agree to maintain certain conservation practices for this period. In addition, the landowners may receive cost-share payments for installing certain approved practices at a rate of 50% of the actual cost (not to exceed some upper limit). Tree planting of both conifers and hardwoods are practices under this program. Up until this year DNR foresters prepared the planting plans. Rates are set in a handbook, and only approved species may be planted. As of this year, because of program direction, DNR foresters will not provide technical assistance for the conifer tree planting practice nor will the state nursery provide seedlings for this practice. This year over 8,000 acres were enrolled in tree planting practices.

CREP—This program was developed to be an enhancement of the existing CRP program by addressing problems that kept landowners who should be using the program from applying. states are required to develop a state version of the program, submit it to U.S. Department of Agriculture through the governor of that State, and get approval before they can get any funds for the program. Although Wisconsin was and is very interested in the program and the potential funding, there have been obstacles to developing a program that all the necessary agencies would support. The last I heard a version was submitted to Washington and we are awaiting approval. However, the version that was submitted was a grassland creation program; the only tree planting that would be allowed would be limited to certain riparian areas.

EQIP—Initially, this program was developed to take the place of the old ACP program (a popular program responsible for the planting of thousands of acres) plus add additional components for water quality and agricultural conservation. Wisconsin chose to structure their program towards water quality—specifically, agricultural waste. Tree planting is allowed but not used frequently. Rates vary by county and are set by basin committees.

WRP—This is another program that you may have heard of, but it has not been used for tree planting in Wisconsin. If you work with other states the program will differ with the state. In Missouri, for example, 99% of their restorations are concerned with breaking dikes and planting trees.

FIP—An older program, strictly for forestry, FIP will fund only site preparation, tree planting, and timber stand improvement. Oddly enough, this program is administered by NRCS, not DNR, and is not available in all counties. Counties must meet certain productivity standards and request being added to be included. Once funded at relatively stable and high amounts in Wisconsin, the program now is barely funded at about $60,000 to $80,000 annually. Last year 451 acres were planted.

SIP—Created in 1990 and once funded at levels of $500,000 in Wisconsin, this program still exists but has received no new funds in the past 2 years. There is still money for SIP due to slippage, so you may encounter it, and it may get a new

appropriation next year. Even with no new funds, we planted 1,142 acres in 1999. Rates are set at 65% of cost with not-to-exceed limits.

WFLGP—Developed in 1997, this is the newest program, and it has just completed its first biennial budget cycle. It is administered by DNR forestry and covers a wide array of practices in addition to tree planting. Funded at $1 million annually, it is also the best funded forestry program. Rates are at 65% with no not-to-exceed-rates. We are currently capturing actual costs on practice so that we will have an accurate tool for making estimates in the future. In the first year-and–a-half, 14,342 acres were planted.

Recent studies show that DNR foresters are only reaching a fraction of the NIPF landowners. With the number of landowners increasing, and an additional trend to keep a cap on the number of state employees, fewer landowners will be able to receive assistance from the DNR. There will be continued opportunities in the area of technical assistance and support to private landowners. The DNR recognizes this need and is actively seeking partnerships through contracting, cooperative agreements, and other vehicles. Tree planting is a popular practice both with landowners and politicians, so the continuation of incentive programs for tree planting is fairly certain. New programs are sure to emerge with a new administration.

These trends support numerous opportunities for private industry, in particular nursery growers who want to expand the scope of their businesses. The trends previously mentioned combined with current high demands for tree planting and a need for more locally produced native species and more associated services, set a stage for logical add-on services to nursery operations. Services like practical plan development, site preparation, planting instruction and assistance, and follow-up care could be successfully combined into a one-stop shopping concept. Any of these or other avenues might be appropriate services for your firm to offer. Many other businesses have built themselves up by this type of product or service differentiation, particularly where price is not the key issue for most landowners because it doesn't vary that much. National surveys have shown that what matters is the value the landowner attaches to the service. For instance, if the landowners do not have to wait long months for a DNR forester to visit them, or if they get superior customer service, warranties or guarantees of quality and survival, or follow-up care, you will be providing additional value, which is a great marketing tool.

In summary, there are great opportunities associated with tree planting incentive programs. The keys are to become familiar with the programs, concentrate on working with the stable, well-funded programs, focus on species that will be needed in the future, search out related areas that are not currently being adequately serviced, build your relationships with local foresters, and then aggressively market yourself to landowners who are enrolling in the programs.

Hopefully the ideas presented in this paper will stimulate your thinking and creativity. I hope you will consider taking a more active role in the tree-planting incentives programs in the future.

MENOMINEE TRIBAL ENTERPRISES FOREST REGENERATION EFFORTS

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Key Words

American Indian, reforestation, native species, forest management, herbicides, seed collection

Menominee Tribal Enterprises (MTE) is located in northeastern Wisconsin on the Menominee Indian Reservation, which includes ten townships of mostly forested land. Past fires, windstorms, and logging all have affected the composition and structure of this forest, which brings us to why regeneration on the forest is very important. Stands are regenerated with tree planting or through natural regeneration using shelterwoods.

The forest management goal for this forest is to produce the maximum quantity and quality of sawtimber while maintaining the diversity of native species. The diversity of this forest and the forest management goal require us to use all the forest management tools available to the profession. Silvicultural prescriptions are developed based on vegetative habitat types, the tree species that will produce quality sawtimber on a given habitat type, and stand composition.

Once a stand destined for regeneration is harvested, MTE begins the regenerating process. Planting sites will be allowed to regenerate for 1 growing season, primarily to allow the slash to begin decomposing and the soil seed bank to germinate. They then will be surveyed for the presence of desirable tree species based on the stand's habitat type. Shelterwood stands are left for 2 growing seasons and then treated when seed development in the residual trees is sufficient to regenerate the stand. Surveys help determine regenerated species, stocking, soils, terrain, herbaceous and shrub plants. Stands are regenerated only when there is less than 500 TPA of featured tree species present over less than 75% of the area.

Site preparation for regeneration starts in August. MTE uses a Ponsse Forwarder with Raven Injection Pump and Radiarc Broadcast sprayer. The species composition of the competition will determine the amount of Accord herbicide to use. The range of herbicide applied is 2 to 4 quarts per acre mixed in a solution of 10 gallons of water. Production averages 5.8 acres per hour using this system in both artificial and natural regeneration areas. Four weeks after the sites have been chemically treated, MTE will begin disc trenching or anchor chain dragging. We use a Donaren disc trencher to site prep our artificial regeneration sites. The trencher is attached to the Ponsse Forwarder and can trench 1.9 acres per hour. The trencher has worked well for site prep in both clearcuts and light density shelterwoods. Planting areas are surveyed to determine spacing of planting lines, soil type, slash load, and terrain.

Shelterwood stands are treated using an anchor chain drag with perpendicular drags made across the stand. The first drag knocks back the non-featured regeneration and brush while the second drag disturbs the duff and top soil which results in 80% to 90% of the area being treated. This prepares a perfect seed bed for falling seed. Production is 1 ac/hr for chain dragging.

Trials have been completed using fire as a scarification tool. Fire can be unreliable and it has had good and bad effects. Increased knowledge and correct use enhance our ability to continue to use fire. MTE has used prescribed fire for site prep to regenerate oak, to control non-desirable species, and to reduce slash loads.

In the fall of 1996 we used prescribed fire after herbicide application and the results seem to be excellent. While controlling non-desirable stems, the nutrients released from the ash layer gave the spring-planted seedlings a boost. Two years after the burn, herbaceous plants (bracken fern and perennials) are the only competitors.

Because of site prep, primarily herbicide, competition in regenerated stands the following year is minimal when compared to areas where no site prep has been done.

In order to obtain seed for nursery stock, MTE observes seed development in 3 species: white pine, red oak, and eastern hemlock. This begins in spring using a spotting scope to view the crowns in pre-selected stands looking for immature acorns, cones, and flowers. Once seed development in the stands is confirmed, the stands are monitored throughout the summer.

When the seed is nearing maturity, it is checked to determine cotyledon development, the number of viable seeds, and to determine if insects have destroyed the seed crops. Seeds are sliced in half and magnified through a hand lens or a scope. Trees are then graded within each stand based on the quantity and quality of developing seeds. Each species' seed develops at different rates and needs to be picked before full development, but not until the cotyledons have reached 75% development. The trees are selected and then felled so the fruit can be stripped from their branches, bagged in feed bags, stored in refrigeration between 32 °F and 38 °F, and delivered to the nursery. Red oak seeds are monitored in the same respects as the conifer, but the acorns are collected from superior trees in red oak timber stands after the acorns fall to the ground. Again the seeds are gathered, bagged, refrigerated, and delivered to the nursery. Production and development of each year's crop determine the amount of seed collected.

Some of the oak seeds are kept by MTE and direct seeded at 1,000 to 3,000 nuts per acre the following spring after being stratified in seedbed trays. Trays should not be packed tightly with acorns in order to ensure survival and germination. A fungicide is sprayed over the seed before they are buried 6 to12 inches below the soil surface. Sandy sites are selected for good water drainage.

Seeds destined for planting stock are sent to the nursery. They extract the seeds from the cones and plant them for us. Red oak acorns are directly planted. In 1 to 3 years, depending on the growth schedule for each species, the seedlings are purchased back from the nursery.

Seedlings are mainly ordered through the state nursery, although we have expanded by ordering from private nurseries when the state nursery could not provide seedlings or species. All state orders are bulk orders, which are not graded. Boxed and bagged seedlings are shipped and stored in refrigerated vans. They are graded and prepped based on MTE's culling guidelines. Graded seedlings are dipped in Liquid-gel, re-boxed, and checked for accuracy. Each box is labeled with species, size, date arrived, prepped amount, date, and crew personnel's name and unit number. Plant moisture stress tests are performed randomly on graded and non-graded seedlings. Seedlings that are being planted have to be kept cool on the planting site. Crews use insulated trailers and/or reflector tarps to cover boxed seedlings. Most crews are able to plant 1 to 1.5 acres per person per day.

Menominee Tribal Enterprises plants, on average, 350 acres each year at densities of 900 TPA for conifers and 750 TPA for hardwoods. Inter-planting (fill-in planting) is determined by survival reports. MTE inter-plants when stocking is less than 750 TPA for conifers and 500 TPA for hardwoods. Survival averages around 95%, which is a direct result of chemical and scarification site prep, excellent planting standards, and quality seedlings selected for planting.

Direct seeding has not been as successful. We have only direct seeded in the spring with stratified, germinated acorns. By summer time, squirrels or other mammals looking for food consumed 95% of the seeds. To reduce this, MTE increased the amount of seeds sown per acre, but spring may not be the time to direct seed.

Natural regeneration for Menominee Tribal Enterprises has averaged 17,000 TPA 1 year after site prep. Two years after scarification, the average number of stems decrease by 2,000 TPA. Competition may start to become a concern. All stands must meet the criteria that 75% of the area is stocked with desirable tree species at a minimum of 1,000 TPA.

Shelterwoods are harvested in the winter months when snow and frozen ground can protect the seedlings. Logging crews must stay on designated skid trails and directional fell trees to avoid damage to the regeneration.

Moderate to high competition levels will require a release treatment. For this, MTE has purchased a Silvana Selective mower head that attaches to the Ponsse Forwarder. Desirable regeneration is released by mowing off the tops of the hardwoods that have overtopped it.

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THE MINNESOTA TREE IMPROVEMENT COOPERATIVE

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Key Words

Tree improvement, seed transfer zones, seed orchards, red pine, eastern white pine, black spruce, jack pine, white spruce, progeny tests

As the director of the Minnesota Tree Improvement Cooperative (MTIC) based in Cloquet, Minnesota, I would like to tell you a little about our strategy for creating improved seed, and how individual nurseries or nursery associations can interact with tree improvement programs to the benefit of both parties. MTIC is approximately 15 miles west of Duluth, at the University of Minnesota's Cloquet Forestry Center. The other employees of MTIC are Carrie Pike, the only full time employee, and Jim Warren, a part-time research fellow.

The MTIC was formed out of a unique set of circumstances. The Boundary Waters Canoe Area Wilderness (BWCA) is a vacation destination wholly contained in northern Minnesota and nestled along the Canadian border. In 1979, an addition to the BWCA, called the portal zone, brought the BWCA to its current size of approximately 1 million acres. As a result of this land taking and the corresponding loss of timber income, the State of Minnesota was compensated $1 million/year for a period of 10 years by the Federal government. As part of the plan, the state was to undertake a huge replanting program within and around this new wilderness area to compensate for trees that would no longer be available. As the DNR was responsible for much of the planting, their reforestation program increased tenfold over the next several years. Because similar reforestation efforts were occurring on Federal, State, and county lands, it became obvious to many that there was a need for a central organization to address tree improvement needs in Minnesota.

In 1981, Dr. Carl Mohn of the University of Minnesota, St. Paul, recognized the need for improved seed in regeneration efforts. He wrote a grant to the Blandin Foundation to hire an applied tree improvement specialist and establish the MTIC. The Division of Forestry within the DNR, along with several members from industry, became charter members. The DNR provided some of their federal buyout dollars and MTIC used monies from the original Blandin Foundation grant until approximately 1986, when the MTIC became self-supporting on dues alone.

Currently, the MTIC consists of 25 private and public organizations in the states of Minnesota and Wisconsin. Our membership is divided in 2 groups, "members" and "supporting members." Member organizations typically have at least 1 seed orchard and/or progeny test of their own that they physically manage while MTIC tracks the growth and health of each tree within the plantation, makes recommendations on removals, and conducts breeding activities within the orchards. Supporting members are smaller organizations who generally do not participate directly but who voice their support for tree improvement through their dues and participation at annual meetings and workshops.

Public and private entities are represented at both the full and supporting levels. Public members consist of county land departments, the Iron Range Resources Rehabilitation Board, DNR, the USDA Forest Service, Minnesota Association of Soil and Water Conservation Districts, and the Minnesota Nursery and Landscape Association. Private companies include pulp and paper companies such as Blandin Paper Company,

Georgia-Pacific Corporation, Potlatch Corporation, Wausau-Mosinee Paper Corporation, and Champion International Corporation and lumber companies such as Hedstrom Lumber Company, Rajala Companies, and Itasca Greenhouse. The MTIC oversees about 65 different seed orchards and test sites, which encompass over 90,000 trees and 200 acres (80 hectares) of land. Every tree has a unique identification number that allows MTIC to track the lineage of a particular tree and its location.

The diverse nature of our members and their interest in several different species means that a tree improvement program for each species of interest is beyond the ability of any single cooperator. As a result, decisions are made by consensus of an advisory board, which is composed of every full member. Other "boards" are formed as needed to investigate specific issues and report back to the advisory board. Granted, this is a fairly loose organizational structure, but it works because the members are committed to tree improvement in general, and they recognize the value of pooling resources to accomplish what they cannot do individually. Indeed, some of our cooperators had worked jointly on projects before MTIC was formed, and some continue to do so today and share their findings with the entire group.

The Ecological Classification System divides Minnesota into 3 provinces, the Laurentian Mixed Forest, the Eastern Broadleaf Forest, and the Prairie Parkland. All our activities and cooperators in Minnesota are located in the Laurentian Mixed Forest, which is characterized by a wide variety of soils, climactic conditions, and several different species. This is the forest "breadbasket" of Minnesota, and forestry and forest products are an important sector of the economy.

The vast majority of commercial forest land in Minnesota is located in the Laurentian Mixed Forest province and is divided roughly as 50% private ownership, mainly pulp and timber companies, and 15% to 20% State, county, and federal lands. Native American reservations are part of the federal grouping under the Bureau of Indian Affairs. The MTIC membership has enabled all these groups to incorporate improved seed into their reforestation programs.

The creation of improved seed is neither technically difficult nor a very stimulating research topic like genetically modified organisms, but it does require time, a dedication to the process, and a steady influx of dollars. What follows is a generalized version of a tree improvement program that MTIC has followed with certain deviations for different species.

Any tree improvement plan must start with seeds collected from the wild. Typically, trees are selected that are superior in stem form, disease tolerance, and volume when compared to individuals in the immediate vicinity. These are known as plus trees. Open-pollinated (OP) seeds collected from each plus tree constitute a family, and seeds from each family are kept separate to preserve the genetic identity. Ample OP seeds are collected from these plus trees to grow seedlings in an experimental design amenable to statistical analysis by the analysis of variance method (ANOVA). Measurements on height, diameter, stem form, and disease incidence are made over 5 to 15 years, and the data are analyzed to identify the best individuals. The poorer performers are rogued and the result is a seedling seed orchard that produces seeds that are 5% to 12% better than wild seeds for volume production, depending on species and selection intensity. Gains in other traits, such as stem form and disease tolerance, are often higher than those for volume due to their higher heritability. The best performers in the best families can be selected to make crosses for the next generation, starting the breeding cycle all over again. This type of breeding plan is known as recurrent selection or forward selection because the parents of the next generation are moved forward without being progeny tested.

Individuals from the seedling seed orchard can also be progeny tested using OP seeds in a manner very similar to that used to score the seedling seed orchard. The progeny test is a separate test of the ability of individual trees to produce good progeny, or what we call a test of general combining ability. The OP seeds are collected from individuals, keeping families separate, and planted in a replicated fashion on multiple sites. Measurements are taken and the data analyzed. The results indicate which trees in the seedling seed orchard are good general combiners. The original seedling seed orchard can then be rogued based on this information, and grafts can be taken from these parent trees to establish a grafted seed orchard. This type of

selection is known as backward selection because from the progeny generation one goes back to the parents to create the seed orchard. These selected parents can also be used to create second generation material for advanced generation breeding.

A brief overview of the status of MTIC species of interest follows. Although there is very little genetic variation in red pine, because it is the most planted tree species in the upper Great Lakes region, there is a constant demand for seeds. Cooperators selected plus trees from Minnesota and Wisconsin and created 8 seedling seed orchards of varying ages. Six of these have undergone an initial roguing and are close to reaching sexual maturity as plantations. Because of poor seed crops in the past 8 to 10 years, shortages of red pine seeds are becoming problematic. Short-term interests are to finish initial roguing in seedling seed orchards and to determine a methodology for inducing seed production using gibberellic acid in these orchards to alleviate seed shortages. Long-term interests are to create grafted orchards and determine whether breeding for volume gains is practical. Although red pine has low levels of genetic variation as detected by genetic markers, if gains in volume of as little as 2% to 4% can be realized, then a breeding program can be justified based on the sheer volume of seedlings planted.

Jack pine is a popular reforestation tree because of its rapid growth and ability to survive on xeric sites. Plus trees were selected from Minnesota and 15 seedling seed orchards were established. These have been rogued based on height and stem form and produce seeds on a regular basis due to jack pine's precocious flowering nature. The best individual trees in these orchards were crossed and planted on 4 sites in 1999 to make a second generation population for advanced generation breeding.

The MTIC white spruce program is a hybrid of better Minnesota selections from a seedling seed orchard and superior clones from other tree improvement programs in the Midwest. These superior clones are primarily from Southeast Ontario sources in the Ottawa Valley and were used to establish 7 grafted seed orchards. An OP progeny test was initiated using individuals from the grafted seed orchards and the seedling seed orchard of Minnesota plus trees. Results of the progeny test have been used to rogue the grafted orchards and the seedling seed orchard and determine which individual trees to select for creating improved seed orchards and which trees to cross to generate our second generation population for advanced generation breeding.

Minnesota was once home to towering white pines, but the subsequent generations have been plagued with blister rust, white pine weevil, and deer browse. The MTIC has 1 grafted breeding arboretum of putative rust resistant selections and 3 grafted seed orchards, 2 of putative rust resistant material and 1 with selections for growth and form. Renewed interest in this species has resulted in substantial funding from the legislature and the DNR for a project to increase the tolerance of white pine to white pine blister rust and aid regeneration efforts. The goal is to identify low-to-intermediate rust hazard areas, and then plant seedlings with the highest level of rust resistance possible. Our strategy for increasing rust resistance is to create an early seedling screening system that will identify parents with increased tolerance to blister rust, use histological methods to identify mechanisms of resistance, and then breed individuals with complimentary mechanisms of resistance. Concurrently, we are investigating flower induction methods using gibberellic acid on grafted material to reduce the time to sexual maturity and accumulating putative rust resistant breeding material for screening purposes and deployment into seed orchards.

Early screening work done by Paul Zambino of the Forest Service indicates that resistant seedlings can be identified in 1 to 1.5 years from seed. Histological research by Robert Blanchette of the University of Minnesota has identified 4 to 5 potential resistance mechanisms, and Paula Pijut of the Forest Service has demonstrated that foliar applications of GA4/7 induce flowering in grafted white pine. The MTIC has put out 4 trials designed to field test the validity of greenhouse screening experiments, expanded the breeding arboretum, and grafted new putatively resistant germplasm and deployed it into seed orchards and the breeding arboretum. The MTIC is also responsible for the coordination of all field trials and design of seed orchards.

A white pine blister rust hazard map was created by T.N. Brown, M.A. White, and G.E. Host of the Natural Resources Research Institute, University

of Minnesota, Duluth. It was created using inventory information, climate, topography, distance to water, and several other factors. It updates the original 1961 rust hazard map using modern GIS techniques and therefore works at a smaller scale. For example, some areas rated as "very high hazard" in the old map are now classified as intermediate or low hazards. This map can be found at http://oden.nrri.umn.edu/rustmap/final/BITSreport.html.

Black spruce was one of the first species MTIC worked with using plus tree selection to establish 4 seedling seed orchards and clonal selections to establish 3 grafted seed orchards. All of these orchards produce copious amounts of seed that currently meet the needs of the individual cooperators.

The reason that I, as a tree improvement person, and the Northeast Area Nursery Conference should be interested in tree improvement programs is that they provide seeds that are improved for growth rate, stem form, and disease resistance. In the case of exotic species, where adaptability to local climates is an issue, tree improvement cooperatives can provide information on the best available seed sources. The traits of interest to pulp and lumber companies are the same traits of interest to nursery growers. Organizations join and remain members of MTIC not out of some altruistic sense of duty but rather because they realize that improved seed is a better alternative, and better alternatives increase profits.

You are all encouraged to investigate tree improvement cooperatives and decide for yourself what level of participation is best for your organization. Some nurseries do participate at the full level and host or cohost seed orchards with another member. They can help to shape the direction and research that the cooperative undertakes. Others prefer to participate at a sustaining level, and this provides them with access to research information that the cooperative generates. Regardless of the level of participation, your involvement in a tree improvement cooperative sends a clear message to others in your profession and to state and local governments that tree improvement is a worthwhile activity and economically beneficial.

Another benefit of participation is that there is a constant need for someone to grow seedlings for progeny tests and comparison trials and to graft scions for seed orchards. And as most pulp and timber companies close down their in-house nurseries, there is a need to grow seedlings for operational plantings. In short, belonging to a tree improvement cooperative can be good for business.

Even if you decide not to participate directly in a tree improvement cooperative, you can still seek out and purchase improved seed or seedlings for your nursery operations. State nurseries often have access to improved seed, and other cooperative members may be willing to sell their surplus seed. Generally the increased cost is nominal and it can be retailed as improved seed.

WESTERN FOREST AND CONSERVATION NURSERY ASSOCIATION CONFERENCE

KAILUA-KONA, HI

AUGUST 21—25, 2000

Opening Remarks Presented to the Western Forest and Conservation Nursery Association Conference

Carl Masaki

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Key Words

Hawaii, threatened and endangered, invasive species, native plants, quarantine

Aloha Kakahiaka, Buenos Dias, Guten Morgen or however you may say good morning. It's so wonderful to see so many of you, especially those that have traveled from foreign countries to be here to learn and share your experiences in the nursery area. On behalf of Mike Buck, Division of Forestry and Wildlife (DOFAW) Administrator, welcome to the Western Forest and Conservation Nursery Association meeting here in Kailua-Kona, Hawaii. My name is Carl Masaki, and I'm the forestry program manager for the Division of Forestry and Wildlife, Department of Land and Natural Resources, State of Hawaii. We thank you for coming to Hawaii to share your knowledge on nursery operations with us. Please enjoy the local culture. Today starts the formal part of the meeting, and I'm really impressed with the agenda the program committee has prepared for us. We have local, national, and international presenters. An additional conference benefit that I find extremely important is the networking with other participants. Take advantage of this opportunity to meet others and share information during the meeting as well as for future reference. Exchange business cards, phone numbers, and e-mail addresses.

The Kamuela Nursery

I have been asked to give an overview of the nursery priorities of the Hawaii DOFAW. Three areas will be covered: 1) nursery operations; 2) threatened and endangered species; and 3) noxious weeds. Let me start by giving you some background information on the Kamuela Central Tree Nursery facility. The Kamuela Nursery was established in 1962 to support the development of a commercial forest industry in Hawaii as well as provide an inexpensive source of windbreak seedlings for the agricultural community. Currently, tree seedlings are produced for DOFAW and public use. In the past, DOFAW use included economic development (trees for timber, chips, and so on), watershed and wildlife enhancement, soil protection, threatened and endangered species propagation, Arbor Day, and game habitat management. Public use included economic development (trees for timber, Christmas trees, chips, resale, and so on), windbreaks, and other similar uses as DOFAW.

During the earlier years, bareroot and bag/can stock was the normal method of producing trees. Around 1977, a system using containerized stock or dibble tubes was implemented to produce seedlings. This change was necessitated by the high mortality rate of bareroot stock as well as the very labor-intensive method of producing seedlings. If a landowner could not plant his seedlings due to the lack of rain, manpower, and so on, he would have had to heel his seedlings in. If the drought continued, his plants would eventually die. Dibble seedlings, being portable, had a much better chance of survival. Production

level for the past several years has been around 250,000 to 300,000 seedlings annually.

Various factors make Kamuela less than ideal for seedling production for the following reasons: 1) Strong winds and cool to cold temperatures; 2) lack of space to expand facilities; 3) lack of convenient air transportation service as compared to Hilo and Keahole airports; and 4) high rainfall. However, the site was selected due to the available land and its proximity to the Kamuela airport.

A reduction in force in 1995 caused the worker level to drop from eight to five people. The operating budget was also reduced and has been going down annually ever since.

When sufficient workers and operating funds are available, the Kamuela Nursery has the space and capacity to annually produce 1.44 million seedlings using its current greenhouse and infrastructure. If the seedlings are not germinated by watering (seeds are only placed in the dibble tubes) at the nursery, but expected to be grown at another nursery facility, annual production can go as high as 5 million seedlings. This would require an investment of material and supplies, which would be reused, at a cost of over $373,000 and the additional hiring of three general laborers and a clerk-typist.

Various threatened and endangered as well as common native species are grown for outplanting and public distribution.

In addition to the nursery at Kamuela, smaller district nurseries exist on all islands. Future direction for the Kamuela and district nurseries will be based on the following objectives:

- Optimize the public investments already made in nursery infrastructure,
- Continued development of the commercial forest industry,
- Support the State's needs for reforestation and restoration on its own lands,
- Encourage landscaping with native plants (Act 73),
- Maintain appropriate constituencies not served by the private sector, and
- Become more financially self-sufficient.

With the recent development of forest tree plantations along the Hamakua coast, and the establishment of private nurseries to produce seedlings for these plantations, the Kamuela Nursery will not process orders for more than 25,000 seedlings for any one entity per calendar year unless there is specific written notification that the existing private nurseries cannot or will not fill the order for trees. Due to its sophisticated equipment, the Kamuela Nursery offers a "sow and go" operation if requested. Here the seeds are sown in dibble tubes and the buyer picks up the trays and germinates the seeds at his nursery. We encourage this method for large orders as it takes up less personnel time and nursery space.

Threatened and Endangered Plant and Animal Species

Hawaii, often referred to as the endangered capital of the world, has 292 threatened and endangered (T&E) plants and 81 T&E animals (40 vertebrates and 41 invertebrates) for a total of 373 species. Even our State flower, the yellow hibiscus, is an endangered species (*Hibiscus brackenredgei*). Our former botanist told me that it would cost approximately a million dollars or more to work with each species. This calculates to $373 million; our total division budget is a little over $12 million for four program areas. These wildlife species are officially listed on the Federal Register and six are being proposed with an additional 121 candidate species just around the corner. Now what does all of this mean to us? A listed T&E species must be protected, including its habitat, and efforts taken to increase its numbers in hopes of delisting it. The dilemma we face here is the sheer number of T&E species and the lack of funding to protect its habitat, let alone trying to increase its numbers in the wild. To increase the number of T&E species, DOFAW amended its endangered plant rules and can now sell T&E species to the public as long as strict requirements are followed. A few of the T&E species, as well as other natives, are very attractive and could hopefully be grown in a residential environment. More research is needed to determine how best to care for these plants. The following are just a few of these species:

- Hawaiian violet
- Lobelia
- Trematalobilia
- Silversword
- Iliau

Act 73, signed into law in 1992, mandates the use of indigenous plants for public landscaping

wherever and whenever feasible. Appropriate signage would accompany these plants for public information purposes. Other safeguards will be taken to protect the native plants in the wild. So far, Act 73 has not been implemented because the agency in charge of this law, the Department of Accounting and General Services, has yet to draft rules to carry out the purposes of this law. When I inquired as to the status of these rules this year, I was told that they are still working on it and will contact us for input. Due to DOFAWs ability to use proceeds from the sales of seedlings from its nurseries, our division could produce additional revenues for its operations. The use of native plants in the landscape makes all the sense in the world because, at one time, these plants were the only ones growing from the ocean to the mountains.

Introduction of Exotic, Invasive Species

Another concern of DOFAW is the introduction by private nurseries of exotic plants that could escape cultivation and become weedy. Many introduced plants have become noxious weeds by: 1) displacing native plants; 2) competing with vegetable crops and fruit trees for water, nutrients, and space; 3) invading yards, gardens, pasture, and so on; 4) killing native trees; 5) acting as carrier for wildland fires; and 6) hybridizing with native plants. It's amazing what people will smuggle into Hawaii—snakes, birds, lizards of all shapes and color, and piranhas and other noxious fish, to name a few. When people do not want their pets anymore, they often let them loose in the forest or streams. When people first moved to Hawaii from the continental United States or from foreign countries, they wanted to have ornamental plants from their previous home in their yards. This is how the majority of noxious plants arrived in Hawaii. Although quarantine regulations are stricter today, plants are still being introduced to Hawaii. Of all of the noxious plants in Hawaii today, the greatest threat is *Miconia calvescens*, commonly called miconia, which is a fast growing tree from South America that was introduced into Hawaii in 1959. It has large, dark-green oval-shaped leaves with a purple underside and can measure up to 3 feet long. The tree, which can reach a height of 50 feet, shades out other plants and thus increases the chance for erosion on slopes. A single plant produces thousands of tiny seeds that spread quickly. Miconia, often referred to as a green cancer, has already destroyed 70% of the forest growth on Tahiti. It is currently found on the islands of Hawaii, Maui, Oahu, and Kauai. Until people learned of the destructive nature of miconia, it was sold in garden shops here. There was an incident in the Kona area where a homeowner refused to destroy the miconia growing in his yard until the State Department of Agriculture officials threatened to take legal action against him. Other noxious weeds include: banana poka (*Passiflora mollissima*), a climbing vine from Andean highlands of South America that "strangles" trees in the forest. Dispersal of this attractive ornamental is primarily by humans and by birds and feral pigs that eat the fruit. The fruit, used commercially in South America as a drink, is found on all of the major islands as well as Molokai. Koster's curse (*Clidemia hirta*), native to the neotropics, aggressively takes over the native forest by overtopping and shading out plants. It grows in dense monotypic stands. Dispersal of this plant is primarily by birds and feral pigs that eat the fruit and by humans who carry the seeds embedded in mud on their boots. Vehicles that are not sanitized can also carry the seeds to other locations. Plants are found in mesic and wet environments from 30- to 5,000-foot (10- to 1,500-meter) elevations. First reported in 1941, *Clidemia* is now found on all of the populated Hawaiian islands.

Quarantines

State Department of Agriculture regulations state, in Chapter 70, "Plant and Non-Domestic Animal Quarantine of the Hawaii Revised Statutes," that plants requiring quarantine shall be delivered to the inspector at the port of entry when brought in as cargo, baggage, or hand carried. Plants imported by the United States Postal Service or other commercial delivery service shall be addressed to the plant quarantine office on the island on which the plants shall be held in quarantine. Everyone who arrives in Hawaii by air or water must also complete a quarantine form. All of you who came here from the mainland or a foreign country, hopefully, filled out a form that asks whether you are carrying any plants, seeds, or animals. Last month upon returning from a vacation to Colorado and California, I also was required to fill out this form. From my personal experience, it does not seem that much emphasis

is placed on having the passengers fill out this form and the flight attendants do not seem to take their role in ensuring passengers fill out the form seriously. No attempt is made to have every passenger or family fill out the form. Forms are collected only from those who hand them to the flight attendants.

I have discussed the issues with the Division of Plant Industry of the Department of Agriculture, the State agency that is responsible for preventing unwanted pests from entering the State. They feel that their hands are tied due to the current laws. When I asked what they would change if they could, here is a list they gave me:

1. Change the privacy law so officials can inspect first class mail. Currently, anyone can mail almost anything as first class mail, and officials cannot open the package.
2. Hire more inspectors who can identify plants and plant seeds. Currently, the agency is understaffed and has few qualified inspectors.
3. Regulate the importation of flower seeds. Currently, anyone can import a small amount of flower seeds as long as the plants are not on the noxious weed seed list.
4. Review the criteria for determining the designation of noxious weeds for eradication or control projects by the State. Currently, some noxious plants do not meet the criteria for being designated as noxious plants due the way the law is written.
5. Institute emergency measures that can circumvent the public input and environmental assessment process, which is so time consuming, when a noxious plant in found. Currently, when an agency wants to change their rules, public hearings are required. In addition, when a noxious weed is discovered, eradication cannot take place until after the environmental assessment process is completed.
6. Reprint the quarantine form in several languages so that visitors can understand it.

Summary

This morning I presented our Division of Forestry and Wildlife's nursery priorities involving nursery operations, threatened and endangered species, and noxious weeds. As in most places, fiscal constraints make nursery operations a challenge. Conferences such as the one for which these welcoming remarks were written give us an opportunity to discuss our problems with other nursery personnel who can help provide solutions. Threatened and endangered species will always be a challenge with us, and we need to find innovative methods for their protection and enhancement. Noxious weeds will always be a challenge for us, and we need to work with other agencies and organizations to plan for the control of these weeds as well as limit the introduction of new species. We need to work with nurseries to determine which species could be a potential weed species before it is brought in. The saying "an ounce of prevention is worth a pound of cure" is so true in this case.

Developing Microbial Inoculants for Native Hawaiian Trees

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Key Words

Reforestation, afforestation, Rhizobia, mycorrhizal fungi

Our nursery grows tree seedlings mainly for nonindustrial projects, usually for people who are reforesting their own property. Our clients generally share 3 characteristics:

- Most are planting on land that is somewhat marginal or degraded: former pasture, old sugar cane land, eroded hillsides, exposed ridges, and so on;
- Most operate on a limited budget, planning for minimal maintenance after establishment; and
- Most have a larger vision for their project than simply creating a stand of trees; they want their trees to survive independently and to reestablish some of the ecosystem value of a forest.

We use certain microbial inoculants in the nursery as a part of supporting the objectives of accelerating rehabilitation of degraded land and ecosystem function, as well as reducing costs in establishment and maintenance of forest plantings. Microbial inoculants re-create natural partnerships between plants and some of the beneficial microorganisms that support plants. Using microbial inoculants is a way to reintroduce some naturally occurring microorganisms that support the productivity of plants in nature. In our nursery, we work with both rhizobia and mycorrhizal inoculants.

The use of rhizobia inoculants for nitrogen-fixing trees, including the native Hawaiian koa (*Acacia koa*) will be discussed in this paper, along with how nitrogen fixation works, why inoculation in the nursery is advantageous, and how to use rhizobia inoculants in the nursery. Information is given about mycorrhizal fungi, whose use has, to date, been limited in nurseries in Hawaii.

For the end user, the tree planter, there can be some tremendous economic and ecological benefits of rhizobia and mycorrhizal inoculants having been used in the nursery. In the case of Hawaiian koa, for example, inoculation can result in faster early growth, with reduced use of chemical fertilizers. Faster early growth also means faster shading of understory and quicker canopy closure, which reduces weed control expenses. Inoculating tree seedlings in the nursery stage can save the people who plant the trees a lot of money in tree establishment, while at the same time reducing the use of some chemical fertilizers and herbicides. Using microbial inoculants can help make it more sustainable, and also more affordable, for people to reforest with species such as the native Hawaiian koa.

The Importance of Rhizobia

Rhizobia inoculants are used for nitrogen-fixing legumes. They are important here because they form partnerships with the koa, which is the most widely used native tree for forestry in Hawaii, as well as a number of other important forestry species including rosewoods (*Dalbergia* spp.), narra (*Pterocarpus* spp.), monkeypod (*Albizia saman*), and other species of Acacias and Albizia.

Rhizobia are also essential for nitrogen fixation, a key process for restoring productivity to marginal or degraded land, where most of our nonindustrial

forestry takes place. Although the terms "nitrogen fixing plants" and "nitrogen fixing trees (NFTs)" are widely used, the plants themselves do not have the ability to make use of the nitrogen gas in the air—it is only through the symbiotic association with rhizobia bacteria that the process takes place. Simply planting leguminous "nitrogen fixing" trees will not ensure that nitrogen will be accumulated; the process of biological nitrogen fixation depends on the plant forming a partnership with the correct rhizobia bacteria.

Biological Nitrogen Fixation

Nitrogen is usually the most limiting element in production, and one of the most expensive to purchase as fertilizer (NifTAL 1984). There is an abundant supply of nitrogen in the air (the air is 80% nitrogen gas, amounting to about 8,000 pounds of nitrogen in the air over every acre of land, or 6,400 kilograms above every hectare). However, the nitrogen in the air is a stable gas, normally unavailable to plants. Many leguminous plants are able to utilize this atmospheric nitrogen through an association with rhizobia, bacteria that are hosted by the root system of certain nitrogen-fixing plants.

Rhizobia are able to convert the nitrogen gas in the atmosphere into amino acids, which are the building blocks of proteins. The legume is then able to use this for its nitrogen needs. Rhizobia exchange nitrogen for carbohydrates from the plant. As the plants drop organic matter, or when the plants die, the nitrogen from their tissues is made available to other plants and organisms. This process of accumulating atmospheric nitrogen in plants and recycling it through organic matter is the major source of nitrogen in tropical ecosystems. Various land rehabilitation and agroforestry practices exploit this natural fertility process by using nitrogen-fixing trees.

Why Use Rhizobia Inoculants?

The process of biological nitrogen fixation depends on the plant forming a partnership with the correct rhizobia strain. There are many strains of rhizobia, and each will work only with certain legumes. Likewise, each legume species will only associate with the proper rhizobia. Unless the strain of rhizobia suited to the legume species is present in the soil, no biological nitrogen fixation will take place. In some cases, 1 strain of rhizobia may provide some nitrogen fixation, but will be less effective than another.

For example, with *Acacia koa*, of all the rhizobia strains in the world, only a very narrow range will form an effective partnership with koa. Within that narrow range, there is a tremendous amount of variation in effectiveness: some rhizobia strains form mediocre or poor partnerships with koa, not fixing much nitrogen for the tree. A few strains are highly productive partners for koa, forming abundant nodules, fixing a lot of nitrogen for the tree, and really contributing to its growth. A tremendous amount of research has been done over the past few decades by the University of Hawaii NifTAL Project, matching species not only for compatibility, but also selecting strains to maximize nitrogen fixation and nodulation.

Inoculation in the nursery is about ensuring that nitrogen-fixing plants form the optimal partnerships with select rhizobia that will fix the most nitrogen for that species. Rhizobia inoculants are live bacteria cultures that are applied to seeds or young seedlings, infecting their root systems with the beneficial bacteria.

If we don't inoculate nitrogen-fixing trees with rhizobia in the nursery, and uninoculated plants go out in the field, they are on their own to form a rhizobia partnership. Especially on marginal or degraded land, there are a lot of unknowns. Whether an uninoculated plant will spontaneously associate with rhizobia in the field depends on several factors: 1) if the correct rhizobia for that plant species are present in the soil; 2) if the rhizobia are available in sufficient quantity to infect roots; and 3) if the rhizobia in the soil are healthy and still able to fix nitrogen (researchers have found that over a period of years, rhizobia in the soil can and do lose the ability to fix nitrogen) (Keyser 2000).

However, even if the correct rhizobia is present in the soil, its nitrogen fixing effectiveness (compared to the recommended and tested inoculant strain applied in the greenhouse prior to transplanting) will be unknown-the soil population may consist of mediocre strains. Also, if the bacteria is present in the soil, it may take several weeks, months, or even years for the association to develop, and this delay will cost the tree planter unnecessary time and money in early maintenance.

Using rhizobia inoculants in the nursery ensures that the nitrogen-fixing trees form a highly

effective partnership to support their growth, and also that the partnership forms early in the tree's life so that its early growth and establishment can be accelerated. This can give seedlings a tremendous jump-start when they get to the field.

How Is Rhizobia Inoculant Applied?

Inoculation (infecting the plant roots with the rhizobia) should take place as early in the tree's life as possible, when the tree will most readily form the association. Rhizobia inoculant can be applied to seeds or to young plants. Usually, rhizobia bacteria come in a peat-based inoculant, with billions (10^9) of cells per gram. The inoculant is usually coated onto the seed immediately before planting, or dispersed in clean water and soaked into the planting medium. One hundred grams of inoculant is usually sufficient for 20,000 to 100,000 seeds. The cost is very small per tree inoculated-a fraction of a penny worth of inoculant can replace a hundred or more dollars worth of nitrogen fertilizer over the life of the tree.

If necessary, after select rhizobia strains have been obtained, a crude inoculum can be made in the future from nodules taken from the seedling roots, without the need to purchase additional rhizobia inoculants.

How Can the Effectiveness of Rhizobia Inoculation Be Verified?

When rhizobia are present and nitrogen is being fixed, nodules can be seen on the roots of the plants. Each one of the nodules houses millions of rhizobia bacteria. When a nodule is opened, a pink or red color inside is usually a good indicator that it is active, that biological nitrogen fixation is taking place. Thus the effectiveness of inoculation can be verified easily with the naked eye. The rhizobia will survive and multiply as the plant grows.

Mycorrhizal Fungi

There are other symbiotic microorganisms that can make a significant difference in tree growth. Of these, mycorrhizal fungi are probably the most important. Mycorrhizal fungi form a symbiotic association with many kinds of plants, acting as a kind of conduit for nutrients from the soil to the root. While only a narrow group of plants can form symbiotic associations with rhizobia, 80% to 90% of the world's plant families associate with mycorrhizal fungi, including most subtropical and tropical trees and many native Hawaii species such as koa, ohia (*Metrosideros polymorpha*), and native *Hibiscus* species. It is also a much more generalized association than those formed by rhizobia, because 1 species of mycorrhizal fungus can successfully associate with many plant families.

The mycorrhizal association is known to improve nutrient uptake, particularly of phosphorus. With the help of mycorrhizal fungi, a plant can often take up many times more of certain nutrients than would be possible in the absence of the fungi. Mycorrhizal associations can also improve a tree's drought resistance, salt tolerance, and resistance to both soil pathogens and adverse conditions prevailing on degraded lands. Research with mycorrhizal inoculant and koa has established that inoculation does have a beneficial effect on early koa establishment, giving the trees a "jump-start" in their early growth (Miyasaka 2000).

The use of mycorrhizal inoculants is becoming standard in many areas for forestry and conservation practices, but until recently their use has been very limited in Hawaii. Due to quarantine restrictions and restrictions on the use of imported microorganisms, commercial mycorrhizal inoculants have not been available here. We recently obtained a permit to bring in a commercial inoculant, and have started testing it for effectiveness.

We are fortunate in Hawaii that Dr. Mitiku Habte, one of the world's foremost experts on mycorrhizal fungi, is based at the University of Hawaii. He has developed a method for nurseries to produce their own "crude inoculum" by multiplying inoculum from a starter culture (of *Glomus aggregatum*) in the nursery. A workshop for nurseries interested in learning how to produce mycorrhizal inoculants is planned for the summer of 2001.

Conclusion

Inoculating plants in the nursery allows them to associate with beneficial microorganisms in their early stages of development, when they are most receptive to inoculation. Even if the appropriate beneficial microorganisms such as rhizobia bacteria or mycorrhizal fungi are present in the soil at the field planting site, the unknown quality and the delay in forming this association can cost

the person who is planting the tree in the field hundreds of dollars in establishment costs, while contributing to unnecessary fertilizer and/or herbicide use. In contrast, inoculation in the nursery is very cheap.

When a seedling is supported at the outset by beneficial microorganisms, it is better prepared to survive independently. Using microbial inoculants in the nursery can play an important role in improving both the economic and ecological viability of forest planting in Hawaii.

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NURSERY PRACTICES IN WESTERN CANADA

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Key Words

Container nursery, seedling quality, fertilization, growing regime, stocktype

Forest seedling production in British Columbia began with bareroot production in the 1930s and has evolved to be 95%+ containerized entering the new millennium. Until the late 1970s most production was limited to government facilities. Currently private industry produces 85% of seedlings planted in British Columbia. Production levels are at approximately 300+ million seedlings annually, with 225 million destined for British Columbia lands and 75+ million seedlings are contract grown for customers in other Canadian provinces and US states.

The industry utilizes the styroblock® almost exclusively as the basis for its container system, which lends itself well to mechanization and associated economies of scale. Filling, sowing, and gritting of containers is mechanized at all facilities. Some also employ mechanical seedling extraction, wrapping, and plug-to-plug transplanting. Computerized climate monitoring and control in greenhouses has become the norm.

Driving the trend to mechanization and high technology is the need for large numbers of seedlings of uniform quality to be available for specific planting times. Specification windows are small, leading growers to place a lot of emphasis on establishing and maintaining crop uniformity. Uniformity of form (morphology), function (physiology), and developmental stage (phenology) are paramount.

British Columbia utilizes over 20 tree species for reforestation, in addition to a variety of other native plants for rehabilitation in general. Many permutations are possible, but a forester generally starts with the ecosystem in question and decides on a species and planting window combination. Other stresses or site limiting factors are then assessed, which help to determine minimum seedling size requirements that in turn determine the age and container size necessary for nursery production.

British Columbia contains a large variety of ecosystems (Figure 1). From alpine to coastal,



Figure 1. British Columbia has an assortment of ecosystems.

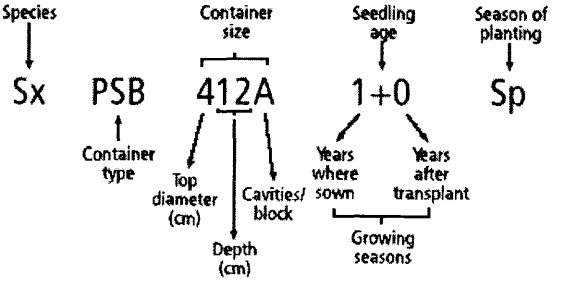


Figure 2. An example of a stocktype label.

prairie to desert, and everything in between, challenges abound. To overcome the large variety in site limiting factors when reforesting requires a variety of stocktypes. A stocktype (Figure 2) is a species/container type (or bareroot)/age class/planting season combination.

Seedling Culturing

Planning

Using known information about the nursery and desired seedling product, a determination is made as to what to plant. Figure 3 shows a growth curve used for this planning. This curve is drawn from right to left, starting with final seedling size (specifications) and planting window (delivery date) requirements. If the stocktype is new, then a hypothetical growth curve is generated using nursery experience and consultation with others.

Knowing a nursery's production capability, one works back from the final delivery date through shipping, packaging, lifting, grading, and growing to determine an appropriate sowing date. Planning also includes seed procurement, preparation, and possible upgrading.

To ensure initial survival and growth, seedlings are planted during phases of active root growth. Root growth potential is highest in spring prior to bud-flush and in late summer and fall after budset (Figure 4). If planting windows do not coincide with natural phases of root growth, then cultural techniques in the nursery are used to shift seedling phenology. The most common treatment used to induce shoot terminal budset is blackout (short-day treatment). Inducing budset also causes a shift of seedling resources from growth to differentiation, resulting in an increase in overall hardiness and stress resistance.

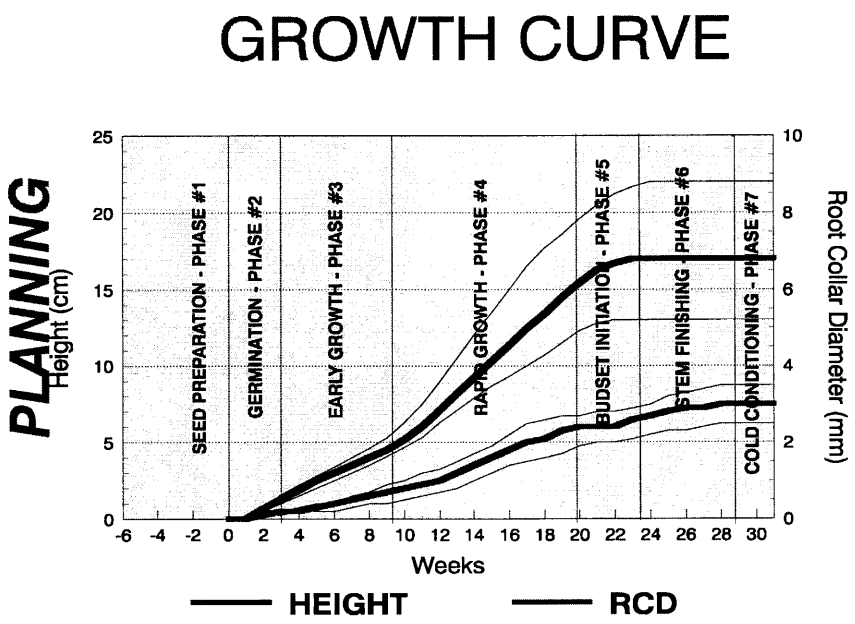


Figure 3. Growth curve used to plan nursery production.

North of the 49th parallel, a greenhouse (Figure 5) is imperative because of climate. To allow production of a variety of stocktypes often requires "growing" outside the natural growing season. Basically, this means extending greenhouse culture at either or both ends of the crop cycle.

The number of hours of sunshine, grower expertise, facility/equipment capabilities, and plant genetics together determine potential biological productivity. Sunshine hours are outside one's control, but the latter three are constantly being upgraded. Computerized greenhouse climate monitoring and control has become the norm, as well as the use of photoperiod control, rolling benches, shade and blackout screens, and so on.

The industry utilizes the styroblock almost exclusively as the basis for its container system, which lends itself well to mechanization and associated economies of scale. Filling, sowing,

and gritting of containers is mechanized at all facilities. Canadian sphagnum peat is the base growing media ingredient; other amendments vary among nurseries.

Sowing

Seed sowing is automated (Figure 7) to minimize seed damage, place seed accurately in the center of each cavity, and reduce the time from first to the last seed sown. This results in more uniform emergence. Each individual step involved during container loading and seed sowing is designed to ensure the creation of a uniform microenvironment for the germinating seed. Prior to sowing, cavities are dibbled to exactly the same depth. Immediately after sowing, a uniform layer of grit (3- to 5-mm depth depending on seed size/container size/seed vigor) is applied as a seed cover, followed by an initial watering to maintain seed imbibition until placement under the greenhouse irrigation system. What drives the trend to mechanization and high technology is the need for large numbers of seedlings of uniform quality to be available for very specific planting times.

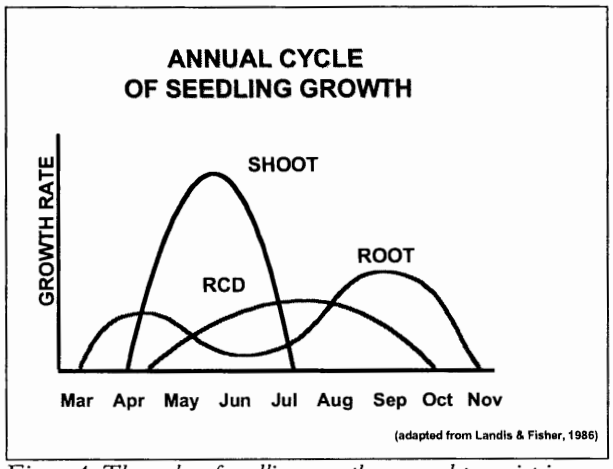


Figure 4. The cycles of seedling growth are used to assist in ensuring seedling survival and growth.

Morphology/Phenology

Morphology (outward appearance) is one measure of quality, and it also functions well for contract adjudication purposes. However, morphological specification windows are small, forcing growers to place a lot of emphasis on establishing and maintaining crop uniformity. Size can overcome physical stresses such as snowpress, vegetation press, and animal browse anticipated at the reforestation site. Figure 8, the scatter diagram, shows a crop with a minimum specification of 15 cm height by 3.2 mm root collar diameter. A maximum height of 35 cm is specified, which, if surpassed, requires a root collar diameter equal or greater than the target of 5.5 mm. Target height is halfway between minimum and the maximum at 25 cm.

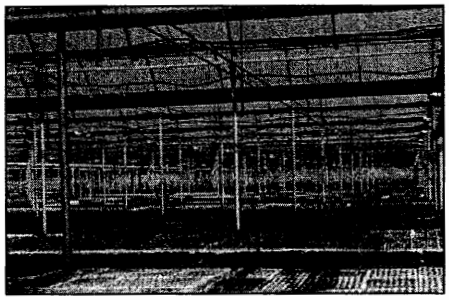


Figure 5. Greenhouse used to produce stock.



Figure 6. Example of newly germinated seed in a container.

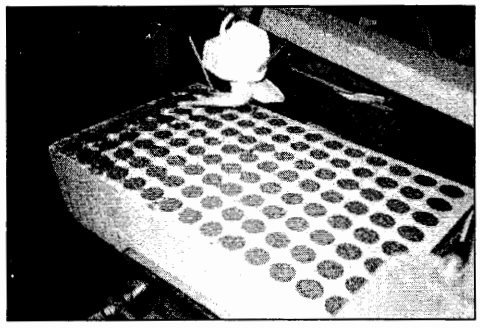


Figure 7. Automated filling ensures efficient loading. Uniform mixing of ingredients, consistent density, and minimal degradation of the peat base are goals.

An added challenge is that quality is defined in several additional ways. Survival and performance require more than just correct morphology. Emphasis is also placed on uniformity of form (morphology), function (physiology), and developmental stage (phenology), with appropriate

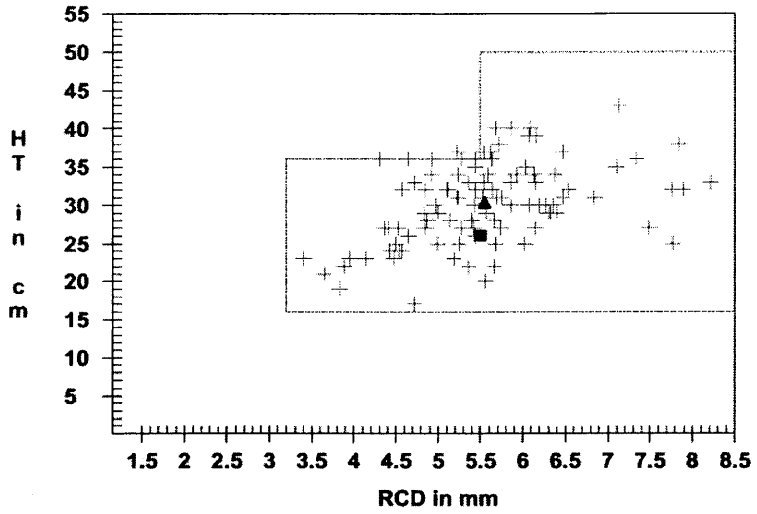


Figure 8. Relationship between root collar diameter to height.

anatomy and growth-differentiation balance expected.

Physiology applies to processes such as photosynthesis, which supplies the energy required to maintain survival, drive plant growth, repair damage, and so on. The machine that converts light energy to chemical energy has to be in top shape!

Phenology is the study of the relationship between climate and periodic biological phenomena such as bird migration or plant flowering. Our industry is concerned with the timing of bud flush/bud induction/root growth phases. Temperate zone plants and their constituent parts go through growth cycles. During the planting phase, root growth cycles need to be on the upswing. The latter assures better access to soil moisture and consequently correlates highly with initial survival, particularly on dry sites. Also, to ensure energy can be allocated to root growth, cessation of shoot growth (a set terminal bud) is preferred.

Anatomy, or internal structure, comes into play when assessing such things as bud viability. Growth-differentiation balance gives an indication of degree of stress resistance that can be expected from a seedling. A woody stem and fully differentiated needles containing a reasonable complement of protective waxes and cuticle thickness is desired to impart increased resistance to mechanical stress, high light intensity and drought. The phrase "Fitness for Purpose" comes to mind.

Uniformity

Since uniformity is a focal point, how do we maximize it? Uniformity is like running a race, it is won (or lost) at the start. The key is establishing it at the beginning and maintaining it from that point on. Step 1 is obtaining quality seed and preparing it such that all of it is ready to germinate at the same time with the same vigor.

Germination environment is next. Since germination is fueled in part by respiration of stored reserves in seed, and respiration rate increases with temperature, germination speed can be controlled. Increasing temperature increases respiration rate and subsequent germination speed which leads to uniform emergence. This strategy is particularly useful when single sowing. Multiple sowing employs thinning as a means of re-establishing crop uniformity early on. When managing the germination environment, it is imperative to manage seed/plant conditions and the boundary layer around the developing seedling.

During the crop cycle, one maintains uniform growth through the application of uniform growing conditions (temperature, humidity, light, CO_2 concentration) around each seedling. Greenhouse climate monitoring and management is paramount. Various tools are used to increase climate uniformity such as horizontal airflow fans and screens. Climate control computers increase strategic options for managing climate. They can anticipate needs based on monitored data and trend analysis and allow for integrated control of

various parameters and equipment. Monitoring during grower absences increases diagnostic capability. Using a built-in weather station, one can utilize light dependent venting/misting/ temperature control, thereby exercising more control over net photosynthesis.

Monitoring

If you are not monitoring you are not managing! Figure 9 shows the continuous decline of K (potassium) over the growing season. An impending deficiency can be easily avoided by acting early based on the observed trend. In Figure 10, Fe (iron) addition causes Mn (manganese) reduction in the foliar tissue sample.

Constant liquid fertigation of all pertinent elements is practiced. Target tissue levels are based on experience, and monitoring serves to maintain optimum levels. For example, foliar nitrogen levels during active growth are maintained between 2% and 3% (of dry wt.). To prepare for overwinter storage, growers target closer to 2% to reduce the susceptibility of foliage to storage molds and *Botrytis*.

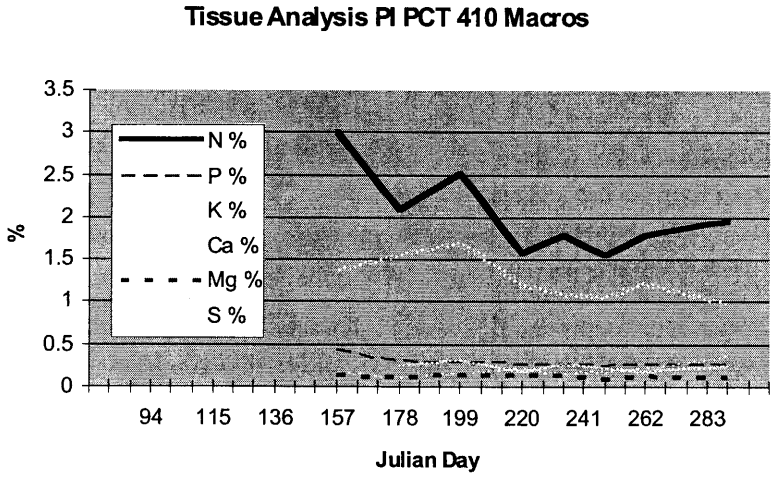


Figure 9. Monitoring trends can allow preventative measures.

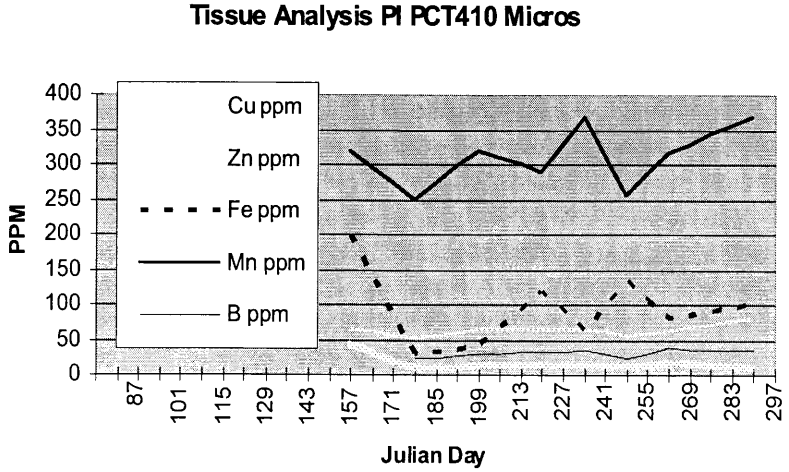


Figure 10. Adding iron can cause a reduction of manganese.

Imparting appropriate phenology for overwintering involves accurate control over budset induction timing. Once achieved, post-bud set induction growing regimes are set up to maintain budset and encourage further differentiation of tissue.

Photoperiod Control

Photoperiod extension is used to maintain vegetative growth (prevent premature terminal budset induction and associated height growth cessation) during the growing season or for high-latitude provenances growing in lower latitude nurseries. Photoperiods of 18 to 24 hours are common. Longer photoperiods are employed on high-elevation and northern latitude provenances. Night-break lighting works as well.

A shortened photoperiod is used to obtain uniform budset induction timing in the whole crop. Ten- to fourteen-hour days are utilized for anywhere from 5 days to 3 weeks, depending on species, provenance, planting window, and nursery location/culture. Longer days work on far-north provenances, whereas shorter days are preferred on southern material. Treatment duration increases with lower latitude and more vigorous provenances.

Dormancy

For final hardening, growers prefer exposure to outside conditions coupled with lowered overall nutrition, utilizing a "finisher" regime.

Finally, mechanized extraction, grading, counting, and labeling may be employed during harvesting. Then, for regular 1+0 seedlings, frozen storage coupled with a quick thaw (to maintain uniformity) finishes the nursery phase.

Conclusion

Stocktype selection focuses on field performance, or "fitness for purpose," with an emphasis on a certain morphology, physiology, and phenology. Uniformity is imperative.

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NURSERY PRACTICES AND RESEARCH IN ONTARIO

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Abstract

A brief history of nursery production of forest tree seedlings in Ontario is presented. The industry dates back to 1904, when the first nursery in the province was established. From 1922 to 1958, eleven additional nurseries were built, the majority of which were situated in northern Ontario. Although the original experiments with containerized seedlings were conducted in 1965, it took more than 15 years for this type of production to become operational. In 1981, the provincial government provided funding for the establishment of private tree seedling nurseries. Today, there are 34 private nurseries in production in the province. Only four of the original government nurseries remain in operation as private enterprises. Containerized seedlings now comprise 80% of all seedling production in Ontario.

Trends and developments in species, stock types, greenhouse structures and container types are presented. Seed sources and overwintering considerations are also outlined. Ongoing research in the province, through LUSTR Co-operative is described.

LUSTR Co-op is a non-profit tree seedling research co-operative, providing research and development services to the seedling industry. The Co-op was incorporated in 1993 and since that time, has expanded to include members from nurseries, forest products companies, allied supply companies, silvicultural contractors, research organizations and colleges and universities.

The mandate and research programme of LUSTR Co-op will be presented. Current and future research trends in Ontario will be discussed.

Key Words

Bareroot nursery, container nursery, LUSTR, stocktypes, containers, tree seedling research

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Ontario occupies an area of 1.1 million km^2 (413,000 mi^2) in central Canada and is the second largest province in the country. Seventy-four percent of the land base is forested; 91% of the forest is owned by the province and the remaining 9% is privately owned. As such, management of forest resources has traditionally been the responsibility of the provincial government.

Nursery production of tree seedlings for the purpose of reforestation in Ontario dates back to 1904, when the first tree nursery was established at the Ontario Agriculture College in Guelph. In 1908, this nursery was moved to St. Williams where it became the first provincial government seedling nursery.

The First and Second World Wars decreased seedling production but, following both wars, the industry boomed. In the early 1920s, two additional government nurseries were established in southern Ontario. In 1946, the government built two more nurseries, and between 1955 and 1958, six additional nurseries were established in northern Ontario. Up until this point, all seedlings produced had been bareroot stock.

By 1960, annual production was up to 50 million bareroot seedlings. In 1965, production of the first containerized seedlings was attempted in what were known as "Ontario tubes." These tube seedlings did not flourish, due in part to lack of interest and expertise. By 1972, production of

Ontario tubes had decreased to an all time low of 2.9 million seedlings.

However, two major problems in production of bareroot seedlings resulted in the resurgence of containerized stock in the 1970s. These were low germination and survival rates and the development of multiple leaders, especially in black spruce, known as "cabbage heading." It was found that the production of containerized stock in the controlled environment of a greenhouse could alleviate both problems.

The container stock was produced in paper pots and Spencer-Lemaire Root Trainers® in an effort to find a method that would either biodegrade after planting or produce a root plug. By 1979, production of container stock had increased to 7.9 million seedlings.

In 1981, the provincial government put out a tender for interested individuals to establish private container tree nurseries. The government guaranteed contracts for the first three to five years of operation. By 1986, production had reached the level of 69.4 million bareroot seedlings and 7.6 million container seedlings.

Today, there are 34 private nurseries in operation, which produce all of the seedlings required for the province's reforestation effort. The province plants approximately 100 million seedlings each year, 90 million of which are containerized. Four of the former provincial nurseries still produce tree seedlings under private or township ownership. The remaining eight nurseries are closed.

The provincial government no longer produces seedlings or is responsible for reforestation. This responsibility has been given to the forest products companies, which have long-term agreements with the government. The government has taken on a regulatory and monitoring role.

The private nurseries have undergone many changes since the early years of the 1980s. Most complexes are now either free standing or gutter connected, poly-covered greenhouses. Seedlings are grown in a wide variety of containers, including BCC Sideslits®, Beaver Plastics Styroblocks®, IPL Multipots®, Jiffy pellets®, Panth Starpots®, or Spencer Lemaire Rootrainers®. The stock is grown to meet diverse site demands, from tiny miniplugs on shallow soils to large, bareroot replacements for competitive sites.

Some of the growers overwinter their stock outside under snow cover. This is the system that has been used since the early days of container production. Many of the growers, however, prefer to store their seedlings in cold storage units over the winter in order to have better control over storage and thawing temperatures. In this system, seedlings are extracted from the containers in autumn and stored in plastic-lined boxes or totes.

The nursery production systems are a mixture of automated and manual. Filling, sowing, and some extraction machines are used. However, large numbers of seasonal staff are often required to complete the filling and sowing lines, fill the houses, and extract the crop for storage. Each nursery boasts unique combinations of equipment and people, from very high-tech nutrient injection systems to hand-thinning crews.

This extremely innovative industry requires research and development to support its activities. As part of the government's restructuring, it is no longer involved in tree seedling research. In an effort to bridge this gap, some far-sighted growers came together in the early 1990s to form a research group, known as LUSTR Co-operative, Inc. The organization was incorporated as a nonprofit group in 1993.

Since that time, the group has expanded to include membership from not only nurseries but also from forest products companies, supply companies, silvicultural contractors, research organizations, colleges, and universities. The co-op's mandate is to determine research priorities and conduct trials; provide technology transfer and support services, act as a communication liaison for the forest seedling industry and partners, and create other opportunities for growth.

In the past five years, LUSTR Co-operative has explored many areas of interest to its members. Trials have been done using mycorrhizae to better prepare seedlings for shallow, stressful, or competitive sites. Development of different stock types, especially larger stock as a bareroot replacement, has been investigated, through transplanting or utilizing large container types. Some work has been done on thawing regimes to determine optimal temperatures and thawing rates for seedlings in order to improve delivery times

without impacting seedling physiology. Lately, work has begun on hybrid poplar clones in an effort to produce shorter rotation crops.

All of this work is geared toward three major initiatives: improved seedling quality, just-in-time delivery, and increased growth and yield. In addition to these areas, the co-op has recently been exploring seed and stock certification options and tree improvement opportunities.

LUSTR Co-operative provides technology transfer to its members in a number of different ways. "From Seed to Forest" is the quarterly newsletter of the co-op, and it contains research results, conference summaries, upcoming meetings, and information on new initiatives. Two workshops are held each year to bring the members together and to present topics of interest. A website is maintained at http://flash.lakeheadu.ca/~lustr/. Literature reviews and personal, on-site visits are done regularly and upon request.

As an organization, LUSTR Co-operative's future focus will be on increasing support from the forest industry and expanding partnerships. From there, the co-op will continue to initiate new, timely research projects and provide pertinent technology transfer. The on-going promotion of LUSTR Co-operative is imperative, as we remain the only Ontario organization focused on tree seedling research.

Forest Nursery History in Western Canada with Special Emphasis on the Province of British Columbia

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Key Words

Bareroot nursery, container nursery, nursery technology, reforestation, privatization

In Canada, forest land ownership and management is largely under provincial jurisdiction, and forestry operations are mainly conducted on public land and not on private land. This public ownership has exerted a profound impact on the development of reforestation policies and nursery technology in Canada.

Collectively, about 650 million seedlings are planted annually in Canada's forests. In excess of 90% of this production is grown as container seedlings, mostly by commercial nurseries.

As most of my experience relates to the province of British Columbia (BC) in Canada, my presentation will largely focus on the nursery history in that province, especially as it relates to the development of container seedling technology and the introduction of private sector nursery production during the 1980s. Developments in the other western Canadian provinces, Alberta, Saskatchewan and Manitoba, were similar to those in BC, but they were generally smaller in scope and their impact on operational practices occurred later.

To start with, let's define what is western Canada. The west to east mid-point of Canada is at Thunder Bay, Ontario, some 3,500 miles east of Vancouver, BC (Figure 1). Hence, the western half of Canada extends into the province of Ontario by some 400 miles. Given this geographic reality, and notwithstanding the fact that inhabitants of that part of our country don't usually see themselves as western Canadians, I will include a few comments about nursery developments in Ontario in my presentation.

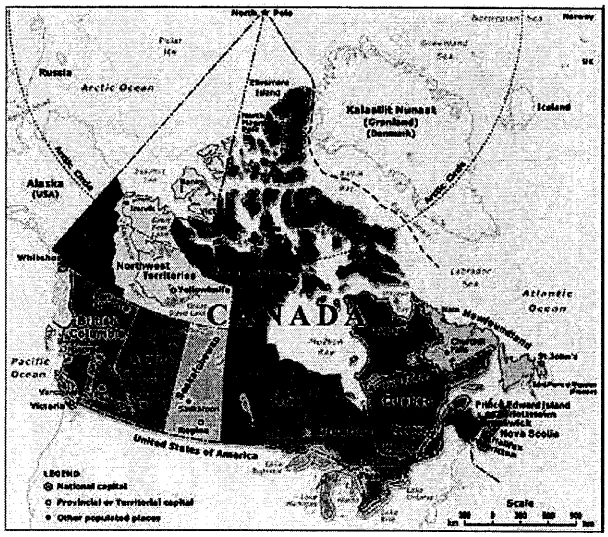


Figure 1. Map of Canada.

Thunder Bay is located on the northern shore of Lake Superior close to the border with Minnesota at Grand Portage. The city is in a major forestry area in northwestern Ontario, dominated by black spruce and jack pine. Forests in the general area support significant regional operations of several major forest companies, including Abitibi, Bowater, Buchanan Forest Products, Domtar, Kimberly Clark, and Weyerhaeuser.



Figure 2. Forest regions of Canada.

To get an appreciation of Canada in a forestry context, one can look at the country from a major species or forest types point of view. The Forest Regions of Canada map (Figure 2) clearly shows the great species diversity of Canada's forests. Due to its variable geological, topographical and climatic characteristics, BC has the greatest number of commercial timber species that are of interest with respect to reforestation. This species-expressed variation significantly impacts silviculture, reforestation and nursery practices.

Speaking about forestry practices, let's now move on to a closer look at western Canada's and, in particular, BC's nursery history.

Nursery and Reforestation History in British Columbia

1926

- Recognition of the need for some research into the growing and planting of coniferous species allowed the establishment of a small Goverment research nursery in Victoria, BC at the southern tip of Vancouver Island—closed in 1932.

1930

- Green Timbers—first production nursery, established near Vancouver, BC.
- An additional 10 production nurseries were developed by the BC Provincial Government through 1985.

1976—1978: Pearse Royal Commission

- Recommends the participation of private sector nurseries in the production of forest seedlings in BC.

1980—1981

- In addition to two existing commercial nurseries, Pelton (mudpacks), and Reid Collins (paper pots), a number of commercial and forest company nurseries start contract growing for the government of BC.

1987

- Most of the responsibility for acquiring seedlings is turned over to the BC forest industry (October 1, 1987).

1988

- BC Government privatizes eight of its eleven nurseries. PRT, our company, buys six of those nurseries.

1998

- Government closes Green Timbers Nursery near Vancouver, BC.

Nursery Development in Alberta, Saskatchewan, Manitoba and Ontario

Alberta, 1997—1999

- Pine Ridge Nursery (1970s)—near Edmonton; bareroot and container; privatized by the government in 1997;
- First (early to mid 1960s) container nursery (industrial) in the province located at Hinton, Alberta, closed in 1999.

Saskatchewan, 1997

- The two government nurseries—mostly bareroot, but with a small volume of container seedling production at one of the two nurseries—are closed/privatized. One (bareroot) nursery is closed permanently. The other nursery (Prince Albert) is acquired and expanded into a complete container seedling operation by PRT. Two other small commercial container seedling operations continue to operate.

Manitoba

- One government-supported nursery (Pineland)—bareroot and container—remains and competes with the private sector in spite of capital funding by the government;
- A container nursery operated by a local Indian Band was closed some years earlier.

Ontario, 1998

- Government closes or privatizes last of its nurseries.

Present Production in Western Canada

With these closures of government nurseries in Ontario, a total of only three nurseries (two in BC and one in Manitoba) remain under management by the government in all of the provinces of BC, Alberta, Saskatchewan, Manitoba, and Ontario. Of the approximately 450 million seedlings that are raised in these five Canadian provinces, about 400 million seedlings are presently grown by commercial nurseries. The remaining 50 million seedlings are produced by the three aforementioned government nurseries as well as three BC forest company nurseries.

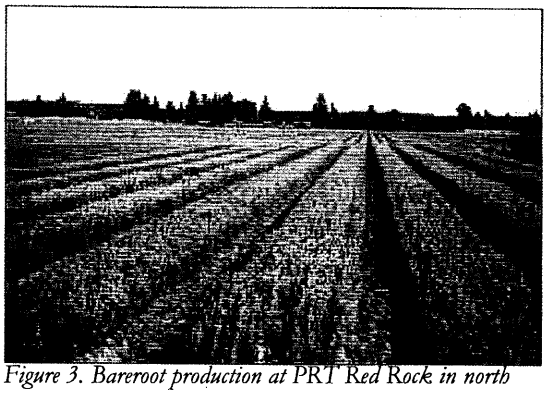


Figure 3. Bareroot production at PRT Red Rock in north central British Columbia prior to the nursery's conversion to a container growing seedling operation.

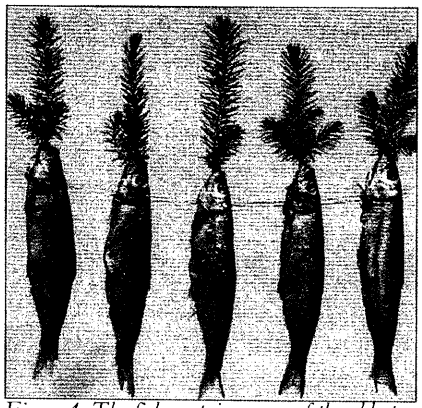


Figure 4. The fish container, one of the oldest plant containers (Source: J.M. Kinghorn, 1974)

Until the mid to late 1960s and early 1970s, bareroot (Figure 3) was the dominant stock type in Canada. Presently, most seedlings in Canada are grown in containers. In western Canada and eastern Ontario, in excess of 95% of the seedlings are, in fact, grown as container stock, predominantly in Styroblocks™.

So what brought about this almost complete change from bareroot to container seedling production?

Rationale for Container-Grown Stock

- Effectiveness of planting versus natural regeneration
- Rapidly increasing planting programs:
  1. Visions of mechanized planting with container stock to facilitate increased planting productivity rates.
- Improved plantation performance:
  1. Difficult species that did not do well as bareroot performed much better and more consistently as container stock. Overall survival improved from the low 60% range to 85% or better.
  2. Improved delivery assurance.
- Conversion from government-controlled production to private sector production:
  1. After the government turned most of reforestation responsibility over to the forest industry, foresters had freedom of choice in ordering their stock types.
  2. Private sector nurseries were willing and able to invest in the required container growing facility infrastructure.

For any of us who harbour notions that container stock was something new or original related to other revolutionary events that took place during the 1960s or 70s, I have sobering news, however. The Aztecs or Incas thought of the idea long before we did (Figure 4).

Development of Container Seedling Production in Western Canada

In Canada, forays had already been made into container production in the 1950s and 60s. In 1959, for example, McLean in Ontario described that the province's production of small container-grown seedlings, raised in "Ontario tubes" (Figure 5), which got up to as high a volume of 20 million

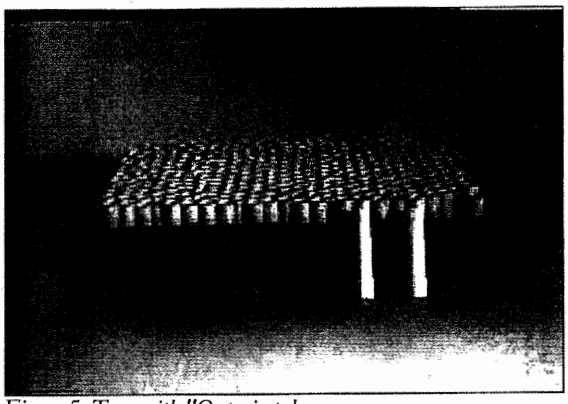


Figure 5. Tray with "Ontario tubes.



Figure 6. Ontario pine tubeling after planting. Note the "one" side slit for root egress.

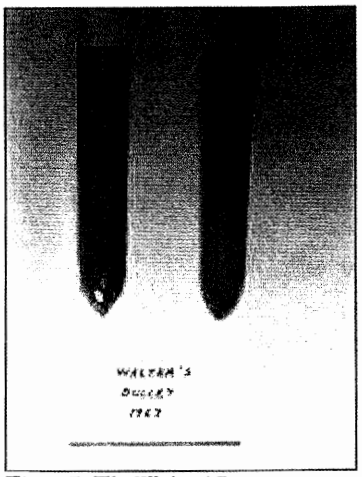


Figure 7. The Walters' Bullet.

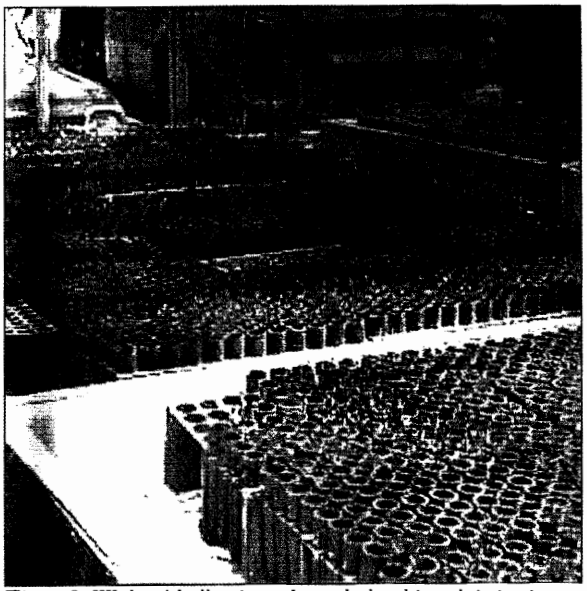


Figure 8. Walters' bullets in racks and placed in sub-irrigation tanks.

seedlings and then rapidly fell out of favour. This "tubeling" system (Figure 6) was not dropped because of the small size of the containers, but as a result of deficiencies in seedling size and quality and consequent poor plantation performance.

In BC it was the pioneering work of J. Walters, a professor at the University of British Columbia's School of Forestry, who invented the Walters' Planting Gun and Bullet (Figures 7 and 8) in 1961 that set the stage for the almost complete conversion from bareroot to container seedling production. Walters envisaged a system where the seedling, with its root system encapsulated in a bullet, together with the planting gun (Figure 9), provided two integral components of a planting tool that would increase planting productivity and ultimately lead to mechanized and precision planting.

Following the lead of J. Walters, J. M. Kinghorn of the Canadian Forestry Service in Victoria, BC undertook the further development of the Walters Bullet System in 1966 and 1967 as a demonstration vehicle for bringing researchers and forest practioners closer together. To this end, he secured the cooperation of the provincial Ministry of Forests and some forest companies to work with his group in the federal Canadian

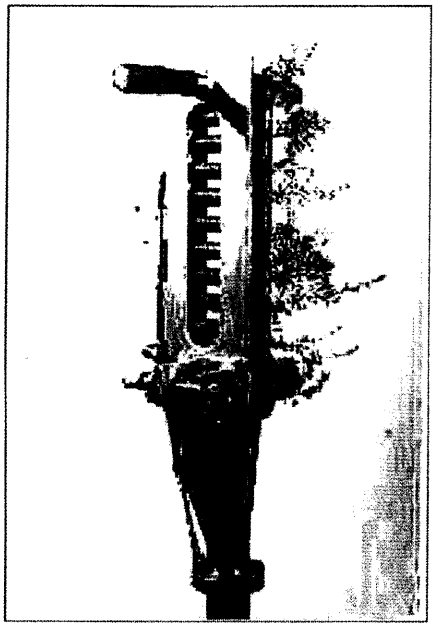


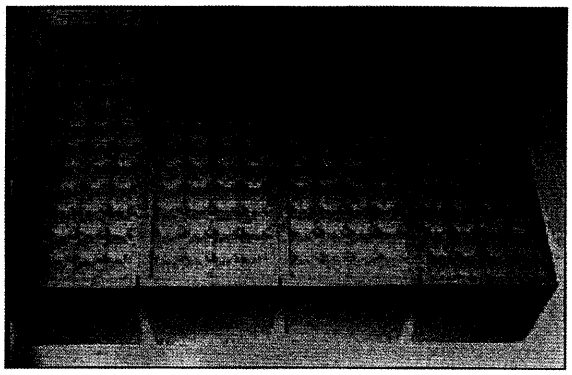
Figure 9. One version of a Walters' planting gun.

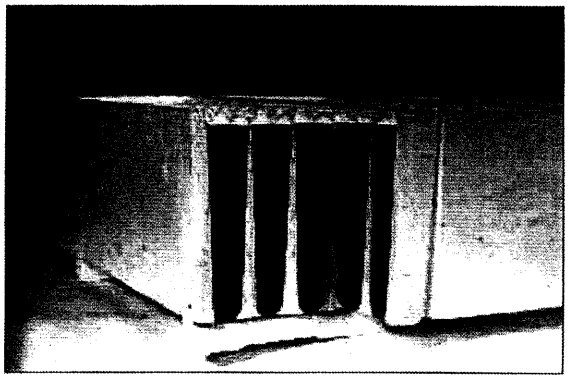


Figure 10. Walters' bullet, showing root egress of white spruce from the bottom drainage holes and through adventitious rooting over the top of the container, several years after planting.

Forestry Service. Notwithstanding the significantly smaller size of the seedlings in Walters' bullets compared to bareroot stock, initial trial results showed promise for this type of containerized seedling system. However, notwithstanding the fact that the planting gun was designed to sever the bullets into two vertical halves, much like a clam shell, the bullet seedling system was not widely accepted due to concerns over the encasement of root systems by the rigid styrene bullet (Figure 10). As a result of this experience, further trials were therefore conducted to compare the performance of bullet-grown seedlings that were planted with or extracted from ("plugs") the bullet. The results with these "bullet-less" plugs were favorable enough to stimulate the concept and design for a new container system that would permit ready extraction from the container after the seedlings had completed their growth cycle in the nursery. The first of this new, multi-cavity seedling growing container, the "Styroblock™" (Figure 11), were manufactured early in 1970 and field tested in July, 1970 in the northern BC Interior.

"Styroblock™" (Figure 11), were manufactured early in 1970 and field tested in July, 1970 in the northern BC Interior.





Figures 11 and 12. The original styroblock. Note quarter block composite design.

The following chronology details the development and operational implementation of the "BC/CFS Styroblock Reforestation System."

The History of the BC/CFS Styroblock™ System in British Columbia

1961

- Walters Planting Gun and Bullet

1966—1967

- J.M. Kinghorn at the CFS undertakes the further development of the Walters bullet system. Secures cooperation of MOF and some forest companies.

1967—1973

- Growing, testing and planting of Walters' bullets.

During this time, Walters continued with the development and testing of various other container prototypes, including sectional and wood (biodegradable?) bullets as well as planting guns.

1968

- Started extracting some seedlings from the bullets just prior to planting "bullet plugs."

1968

- Contract planting introduced on trial basis.

1969—1970

- Design of BC/CFS Styroblock - Styroblock 2 (2+ cubic inches in volume).

1970

- First planting of 100,000 "Styro-Plugs" in North Central BC in July, 1971 (Figures 13 and 14).
- Styroblock 8 (8 cubic inches in cavity volume) developed.

1973

- Introduced ribbed cavities (Figure 15).
- Extract and package plugs at the nursery and ship packaged plugs to the field (Figure 16).

1985—86

- Introduction of 2+0 container-grown stock.

To Present

- Many more cavity sizes and other features introduced, but basic concepts maintained.





Figures 13 and 14. First operational planting of styro-plugs. Note planting from quarter blocks and backpack carrier and quarter block dispenser.

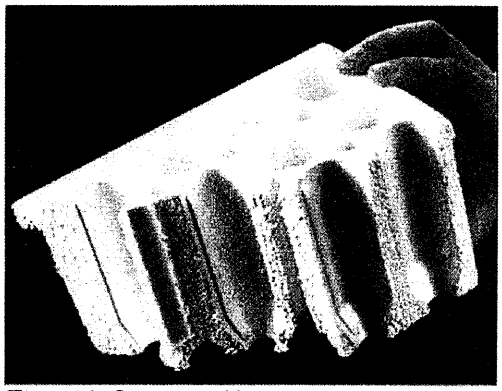


Figure 15. Current styroblock cavity design showing vertical ribs to control root morphology.



Figure 16. Extracted and packaged plugs.

Concurrent with developments in Canada, the Scandinavians, particularly the Swedes, started developing their own hard plastic multi-cavity containers. Although the Swedes and Canadians worked relatively independently, the principal design features of their seedling containers turned out fairly similar.

Numerous other containers have been designed, developed, tried, and adopted, including Ontario tubes, Spencer Lemaire Rootrainers, paperpots, multipots, K-pots, Hiko's, Leach Cells, Supercows, Winstrips, Airblocks, and Jiffy pots, to name just a few. The search for the ideal containers or a need to claim a place in nursery history by developing a new container goes on. There are some good designs, and there are also poorly conceived and designed containers. Unfortunately, this plethora of container types and undue emphasis on just the container rather than on the development of appropriate nursery practices has occasionally hindered the development of effective and efficient container seedling systems and practices in a timely manner.

Well-designed containers are modular, regardless of the cavity size and the number of cavities per block. These multi-cavity containers must be of a size and dimension and filled weight that can be comfortably and efficiently handled by nursery workers without injury, while at the same time allowing for mechanized processing. Cavities must be of a design and have features that prevent root spiraling. Overall, containers must allow for sound cultural and hygienic nursery practices, which are conducive to the production of high quality seedlings with high survival and growth potential. The containers must lend themselves to economical modification in cavity size and density, be reusable and have a reasonable long life of four to five years. Containers that require various parts to be assembled and/or must be replaced every year are costly to handle and purchase, and do not meet essential criteria for efficiency.

In BC, we have done extremely well with the Styroblock™ and that container is used as the system of choice in Alberta, Saskatchewan, and areas of Ontario, the Pacific Northwest US, Mexico, as well as many other places.

Reasons for Wide-Spread Adoption of Container-Grown Stock in BC and Canada

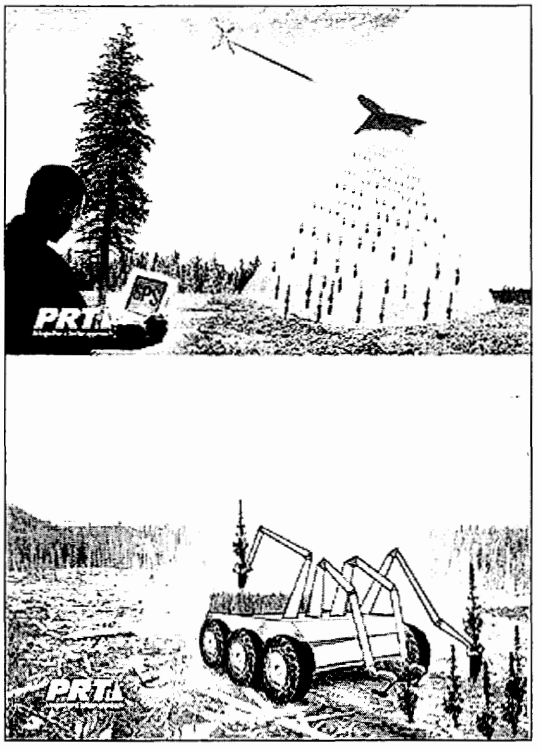
- Early realization that size (Figure 17) and quality are equally important for the field performance of container-grown stock as they are for bareroot; fitness for purpose applies to container-grown stock just as it does to bareroot stock.
- Innovation, and early emphasis on biology rather than engineering, followed by gradual transition to production that is dominated by commercial operators.



Figure 17. The change from micro-seedlings in mini-containers to robust seedlings has contributed very significantly to the success of container seedling production and planting, especially the Styroblock™ system, in western Canada.

- Adoption of one container type by the entire industry for a long period of time, which provided a common basis for effective information exchange and extension work.
- Species, several of which were very difficult to grow as bareroot.
- Early awareness that container-grown seedlings that are planted "container-less" need strong and cohesive root systems that maintain plug integrity during harvesting, handling and planting.
- Predictable and consistent field performance.

- Improved delivery assurance.
- Short lead times to production and shipping.
- Improved planting productivity.



Figures 18 and 19. The future of planting.

THE FUTURE

No one is certain what the future will hold, but many believe that it will change, perhaps drastically (Figures 18 and 19). Current container systems will probably be replaced, but this is not likely to happen any time soon. And in time, nurserymen might be able to grow still better stock. The question is asked: Will container seedling plantations in western Canada "all fall down" because of their heavy root systems, as some have direly predicted? It's been thirty years since we started planting container-grown seedlings and... I am still waiting.

Although seedling physiology remains a popular subject of study at universities and research institutions, apart from a few basic qualitative tests, the assessment of seedling quality still relies significantly on measurement of size and morphology. I am confident, however, that our improving knowledge of seedling physiology as well as our advances through applied genetics and genetic transformation will enable us to enhance growth potential both significantly and physiologically, and it will morphologically tailor seedlings to very specific conditions of site, environment, and time of planting. Science and biotechnology will also allow us to address the issue of pests more effectively and impart resistance or immunity against many plant diseases and insects, and permit more efficient extraction of in situ nutrients both in the nursery and in the field.

Notwithstanding the progress that has been made to date and that will be made in the future, as foresters and nurserymen we must always understand that:

"A poor tree well planted is better than a good tree poorly planted, but a good tree well planted is best." (Source: Jack Long, distinguished and long-retired nurseryman with BC Ministry of Forests.)

CHEMICAL ROOT PRUNING OF CONIFER SEEDLINGS IN MEXICO

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Abstract

Many countries grow seedlings for reforestation in polybags where root spiraling and root egression can decrease seedling survival and growth following outplanting. The overall objectives of this study were to investigate the effect of chemical root pruning on root spiraling, root egression, and nursery performance of *Pinus pseudostrobus*, *P. montezumae*, and *P. greggii* seedlings and in addition, evaluate the effect of morphological characteristics of those seedlings on survival and field performance after outplanting. This research was carried out in 2 nurseries located at New Mexico State University, Las Cruces, New Mexico, and at Colegio de Postgraduados in Montecello-Texcoco, Mexico. Seedlings were grown either in SpinOut®-treated or untreated polybags. Additionally, cultural practices such as growing mixtures and drainage design were also evaluated. In general, seedlings grown in copper-treated polybags had greater height, root collar diameter, and biomass production. Copper treated polybags practically eliminated root spiraling at the bottom of polybags and consistently had less root egression from the bags. In many cases, seedlings exposed to copper had higher root:shoot ratios because of less root egression. Among the treatments evaluated, the combination of copper-treated polybags and copper-treated cloth was one of the best, possibly because this treatment eliminated root spiraling and root pruning is an important cultural practice that can be used under traditional production systems in Mexico to improve seedling quality and consequently improve field performance.

Key Words

Polybags, seedling production, seedling quality

During the last three decades deforestation has become one of the most important ecological problems in Mexico. To counteract this problem, the Mexican government recently has implemented an aggressive reforestation program, including the planting of more than two hundred million seedlings of different species each year. However, more than 60% of those seedlings are still produced under the traditional production system using polybags. In this production system, problems related to poor drainage media, root egression, and root system malformations are common.

Most nurseries in Mexico still use forest soil as the principal component of the growing medium for polybags (Sánchez-Velázquez 1995; Mexal 1997). Sometimes this medium is amended with sand or with small portions of other components but often is used without any amendments. Furthermore, this medium is heavy and often creates a compacted and poorly drained rooting environment, which further reduces root development within the bag (Mexal and others 1994; De la Garza-López 1995).

Root egression is another common problem in polybag production system. In general, seedlings in polybags are grown side-by-side on the ground. Under these conditions, roots escape the polybag through drainage holes and grow into the soil. These plants utilize the nursery moisture and nutrient runoff in the soil below the bags and therefore grow faster. However, at harvest, these

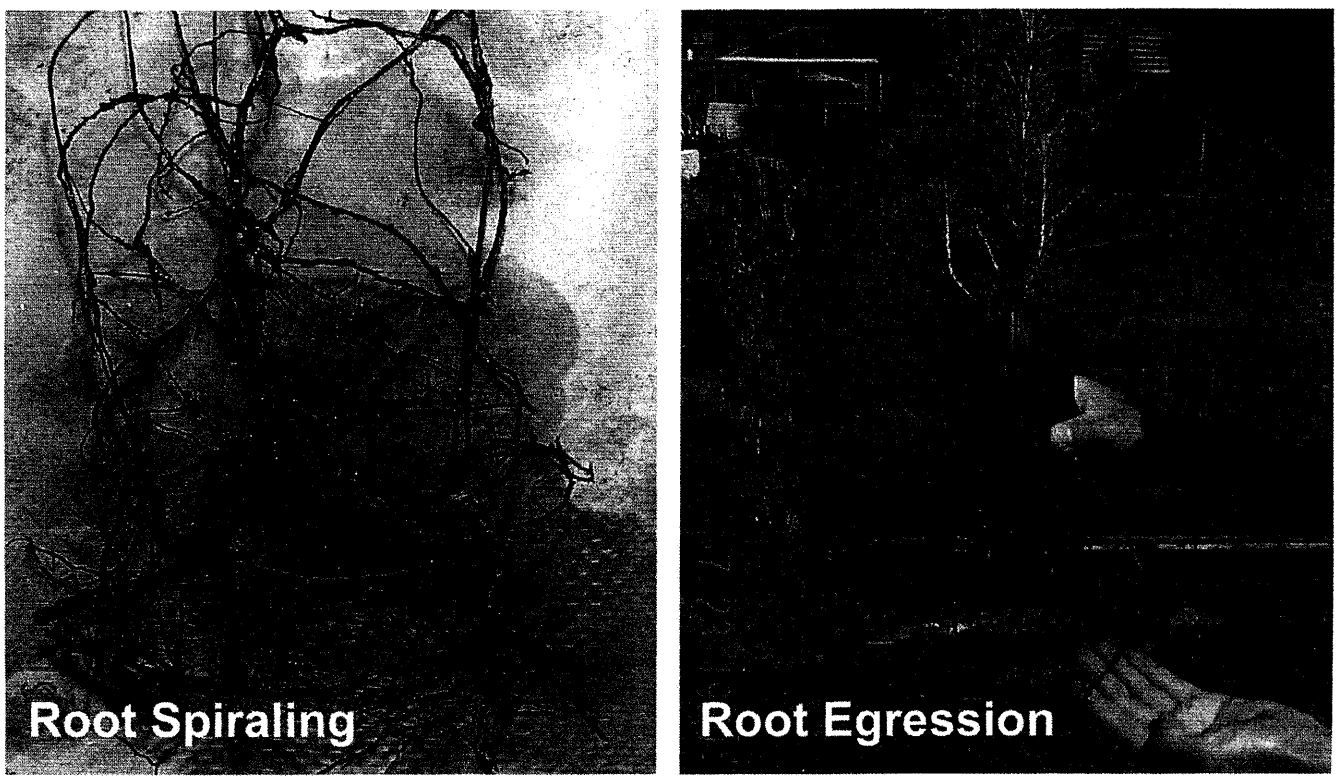


Figure 1. Root spiraling at the bottom and root egression are two common problems associated with the traditional nursery seedling production using polybags.

roots are torn from the plant and left in the nursery beds. Thus, many plants are shipped to reforestation sites with damaged, deformed, or poorly developed root systems that can decrease outplanting survival and growth (Stein 1978). This is a common problem throughout Mexico, even though nursery manuals (Patiño-Valera and Marín-Chávez 1993) recommend lifting the bags to prune the escaping roots at regular intervals. However, few nurseries actually do it.

Nursery production systems using polybags have been also traditionally linked to root system malformations (Josiah and Jones 1992). Furthermore, polybags are considered as poor containers to produce quality seedlings by some (Venator and others 1985). Polybags promote lateral root spiraling and taproot deformation (Figure 1). Container walls tend to change the natural development of lateral roots resulting in malformations that may affect the future development of the plants (Arnold 1996). Therefore, seedlings that develop spiraled root systems may grow poorly some years after outplanting (Bell 1978).

Nursery techniques that produce well-developed, fibrous root systems contribute to overall improved seedling survival and growth (Struve 1993). In natural settings, many conifers develop a lateral root system near the surface (Stein 1978). These roots improve the anchoring and stability of the tree (Burdett 1978) and provide sites for mycorrhizal infection because of their proximity to the soil's microorganism-rich organic layer (McDonald and others 1984). For nursery-grown seedlings, the number and distribution of lateral roots is positively correlated to outplanted seedling performance (Mexal and Burton 1978).

One cultural practice that has been successfully used to control root development and to reduce root malformations is chemical root pruning (McDonald and others 1984; Arnold and Young 1991; Schuch and Pittenger 1996). The application of copper to the interior of containers avoids malformations of the root system and promotes

the growth of new lateral roots (Struve and Rhodus 1990). Chemical root pruning using copper treated containers has been documented for many species (Struve and others 1994; Armitage and Gross 1996; Arnold 1996; Crawford 1997) grown principally in United States and Canada. However, little work has been done with chemical root pruning using polybags.

The overall objectives of this study were to investigate the effect of chemical root pruning on seedling quality and nursery performance of *Pinus pseudostrobus*, *P. montezumae*, and *P. greggii* seedlings, and evaluate the effect of morphological characteristics of those seedlings on survival and field performance after outplanting.

The Study

This research was carried out in nurseries located at New Mexico State Unversity, Las Cruces, NM and at Colegio de Postgraduados in Montecillo-Texcoco, Mexico. Three important Mexican pine species, *Pinus pseudostrobus*, *P. montezumae*, and *P. greggii*, were included in this study. Seedlings were grown either in SpinOut®-treated or untreated polybags. Griffin Corporation (Valdosta, GA) provided all polybags. The active ingredient in SpinOut® was copper hydroxide ($Cu(OH)_2$) at a concentration of 7.1%. In addition, other cultural practices such as different growing mixtures and drainage design were also evaluated.

We used two different sizes of polybags: 20 X 10 and 22 X 16 cm where the first dimension is the length and the second is the width of the flattened bags. Thus the width is one half of the circumference. The experiments at New Mexico State University used a commercial medium, Metromix® 702 (50% to 60% composted pine bark fines, 15% to 25% Canadian sphagnum peat moss, 10% to 15% medium grade horticultural vermiculite, and 5% to 15% horticultural perlite). In the case of the experiments established in Mexico, local materials such as forest soil and sand were used in different proportions.

The experimental designs varied according to the objectives of each individual experiment but for all experiments the variables evaluated were survival and the morphological parameters height, root collar diameter, root volume, root dry weight, and shoot dry weight. Shoot and root dry weights were determined after seedlings had been oven dried for 72 hours at 60 °C (140 °F). In some of the experiments, one half of the seedlings produced from each treatment were used for outplanting trials.

Results

Root systems of seedlings produced in copper-treated polybags were visibly more fibrous than non-treated seedlings. These results agree with earlier studies in other species (Wenny and others 1988, Arnold and Struve 1993). More importantly, copper-treated polybags effectively minimized root spiraling and root egression from the polybags. This may help explain the increase in root dry weight for the three species with copper treatment, since most of the roots were kept inside the polybags resulting in a more uniform and efficient distribution of the roots throughout the growing media. In this way, seedlings were able to acquire nutrients and water more efficiently resulting in growth increases. Similar results were found for different species of conifers (Beeson and Newton 1992; Dumroese and Wenny 1997) and hardwoods (Arnold and Struve 1993; Schuch and Pittenger 1996).

For the three species, copper-treated polybags improved morphological characteristics (for example, root collar diameter), which have been linked to outplanting success for bareroot seedlings (Mexal and Landis 1990). Increases in root collar diameter and biomass in combination with reduction or elimination of root spiraling and root egression may also increase the possibility of survival and successful establishment of polybag seedlings after outplanting. Biomass production was improved for all the species produced in copper-treated polybags. For *P. greggii*, there was an increase in height, root collar diameter and root:shoot ratio, for *P. pseudostrobus* there was an increase in root collar diameter and root:shoot ratio, but for *P. montezumae* root collar diameter was increased.

In the case of drainage patterns evaluated for *P. pseudostrobus* and *P. montezumae*, the results did not show a clear tendency. This may result from the growing medium used for this study. The medium not only had good drainage but also high water retention capacity. This could be the reason why even in the more restricted drainage pattern, water accumulation, and thus drainage problems, were avoided. On the other hand, polybags within the other extreme of drainage patterns (open bottom)

did not show any problems due lack of water. However, in the case of *Pinus greggii* produced in Mexico using traditional growing medium (forest soil amended with different proportions of sand), there was a significant interaction between chemical root pruning and the media used to produce the seedlings. In general, chemical root pruning works well with mixtures containing good drainage. On the other hand, when media drainage was poor, no differences were found between copper-treated and non-treated seedlings. In addition, drainage design significantly affected the morphological variables evaluated. In general, the more drainage the better the nursery performance of the seedlings.

Conclusion

Seedling quality can be improved by applying suitable cultural practices during nursery production. These practices, such as chemical root pruning, directly impact the root system resulting in an improvement in seedling quality. It is easy to assume that developing a better root system of the seedlings may increase the opportunity of these to survive after outplanting, and it is possible that increasing seedling survival may help in decreasing the deforestation rate in Mexico.

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CLONAL PROPAGATION OF EUCALYPTUS IN BRAZILIAN NURSERIES

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Abstract

Brazil has established extensive *Eucalyptus* plantations to support a growing forest products industry. During the past 25 years, the country has been a pioneer in developing clonal propagation systems to regenerate these highly productive plantations. Original clonal selections optimized disease resistance, coppicing ability, and volume growth, while recent priorities have moved to improve volume growth and wood quality. The techniques used for the establishment and management of clone banks has seen fundamental changes during the development of clonal systems. From early clone banks, established at wide spacings over large areas, there has been a gradual shift to intensively managed smaller units. The evolution in clonal techniques has increased planting stock quality and lowered prices. Brazilian industrial programs commonly produce millions of cuttings from tissue culture techniques and intensively managed hedges in green houses. Specific technologies have been developed regarding container medium, fertilization, and environmental management. These technologies are typically produced through cooperative industry and academic programs.

Key Words

Vegetative propagation, clonal orchards, rooted cuttings

The word "Brazil" often conjures up images of Rio de Janeiro, Carnival, sparkling white sand beaches, and the Amazon River. But Brazil has much more to offer, namely a significant and highly productive forest products industry. Most of the forest industry concentrates in the southern one-third of the country between 20° to 30° south latitude, particularly the states of São Paulo, Minas Gerais, and Bahia. Brazil is a large country, and forestry plantations can be found in the northern part of the country near the equator as well.

Although Brazil grows loblolly, slash, and Caribbean pine, the *Eucalyptus* planting program is over 80% of the total annual planting program, according to the Brazilian Pulp and Paper Association (BRACELPA 1999). *Eucalyptus* is used for pulp and paper, charcoal, and some solid wood products. The more commonly planted *Eucalyptus* species are *grandis*, *urophylla*, *saligna*, and several hybrids, particularly *grandis x urophylla*, or *urograndis*. Rotation lengths are normally five to eight years while average growth rates are reported at 20 to 40 m^3/ha/yr. Eucalyptus is cultivated using intensive practices that include mechanical and/or chemical site preparation, leaf cutting ant control, fertilization, hand planting container-grown stock, watering, and chemical, mechanical, and manual weed control (McNabb 1994). A typical planting program is 5,000 to 15,000 ha/year, requiring large scale nursery activities. The majority of this *Eucalyptus* planting program is based on the vegetative propagation of individually tested and selected clones.

Brazilian forestry has been a pioneer in the development of nursery techniques for the clonal propagation of *Eucalyptus*. Originally, clonal propagation was viewed as a method to improve plantation productivity and uniformity, disease resistance, and coppicing ability (Campinhos and Ikemori 1983). The objectives of the program

have gradually changed over the years to emphasize wood volume plus wood quality. Coppicing is no longer an objective, as the rate of clonal selection and improvement results in new clones being planted in successive rotations. Some of the first work on clonal propagation was done in the early 1970s at the Piracicaba campus of the University of São Paulo (Poggiani and Suiter Filho 1974). The process was moved to large scale production forestry by the private sector at Aracruz Florestal in the late 70s and early 80s (Campinhos and Ikemori 1983). The pioneering work of Aracruz has been widely recognized and has resulted in their forestry personnel winning the Wahlenburg prize for advances in forestry technology. Although the current clonal process is basically the same today as it was 15 years ago, there have been significant changes in efficiencies and techniques, particularly in the last five years.

The Clonal Selection and Propagation Process

Individual trees are first selected in existing plantations for the morphological characteristics of growth, health, and branching patterns. Trees can be selected as early as three years after planting. Selected trees are then cut down and the coppice sprouts are used to vegetatively propagate a number of cuttings sufficient for a field testing program. Simultaneously, wood samples are analyzed for wood properties such as lignin content, specific gravity, and fiber length. Clonal tests are conducted on a variety of sites, with each of these sites carefully characterized by thorough in-house soil testing and analysis. Final selection for inclusion in the planting program is based on field performance, nursery performance (including rootability), and wood properties. Once selected, clones are then placed in a clone bank to be used for mass propagation.

The first clone banks used for cutting production were established at a 3- by 3-meter spacing (1,111 plants per hectare) and cultured similar to a plantation (Higashi and others 2000). Each individual plant was managed as a "hedge" with multiple sprouts removed from each stool. One or more stems were usually left to serve as a carbohydrate source for the production of future cuttings. Over time this system developed into a closer spacing at 0.5- by 0.5-meters with 40,000 plants per hectare. Now called a "clone garden," they were moved adjacent to the nursery, irrigated, and fertilized. Each stool was still continually hedged, but cutting production began earlier, and the frequency of harvesting increased. As a result, the ratio of clone garden to area planted increased from 1:44 to 1:525 (in other words, 1 ha of clone garden could produce enough cuttings to reforest 525 ha with planting stock) (Higashi and others 2000).

The sprouts removed from hedges were transported to the nursery and processed into cuttings of 10- to 15-cm lengths in the case of clone banks and 6- to 8-cm lengths in the case of clone gardens. A cutting consisted of a semi-hardwood stem section with a single pair of leaves that were usually cut in half. The base of the stem was dipped in an IBA treated talc (usually 5,000 ppm) and transplanted to the growing container. For the past ten years Brazilian nursery managers have mostly used the "Hawaiian dibble tube" with about a 3-cm top circumference, 10- to 15- cm in length, and around a 50-cc volume. Container medium varies by company but is normally a mixture of composted pine bark, vermiculite, and carbonized rice hulls. It is typically a light, well aerated mixture that is well drained yet having good water retention properties.

After cuttings are planted into individual containers, they are placed under misting in a greenhouse or shade house. Rooting is commonly above 75% and robust enough to grow out of the bottom of the containers during this phase. After approximately 45 days, the rooted cuttings are removed from misting to an area covered with 50% shadecloth. At this point, empty containers (dead cuttings) are removed and the live plants are separated by size. Cuttings remain under shade for an additional 10 to 20 days and then are moved to full sunlight. After an additional 30 days they are ready for planting in the field. During this process, the cuttings are routinely fertilized, usually through the irrigation system. Smaller plants may receive increased fertilization.

One of the most perplexing problems encountered in this system was an increase in the variability of cutting rootability and growth in the nursery. The continual coppicing of *Eucalyptus* hedges resulted in harvesting cuttings of a variety of physiological ages and sizes. The Brazilian nursery community referred to this as the "C effect" and considerable effort was applied to

solve the problem (Xavier and Comerio 1996). While the clonal garden was able to maintain the juvenility of cutting material necessary for successful rooting, over a period of time the degree of juvenility began to vary, resulting in reduced rooting success, variable rooting timing, and increased sorting. All of this translated into higher production costs and lower planting stock quality. The current clonal garden techniques have practically eliminated this effect and greatly increased stock quality.

Current Propagation Techniques

The majority of current *Eucalyptus* clonal propagation in Brazil is based on indoor clone gardens. These gardens are planted in raised beds of fiberglass or concrete 20 to 30 cm deep, 40 to 60 cm wide, and 8 to 12 m long. They are usually filled with washed sand and may be irrigated by internal flow from one end to the other or by drip irrigation from above with drainage at one or both ends. Nutrition management in these indoor clonal gardens is an integral part of their success (Higashi and others 2000), and considerable research has been devoted to finding the most satisfactory combinations of macro- and micro-nutrient fertilization to maximize production.

The clonal material for establishing indoor gardens is initiated and maintained by using tissue culture techniques. Clones that have been identified through the clonal testing program are first established in test tube media under controlled light and temperature conditions. As the explants callous and sprout (they are not allowed to root), shoot tips are removed and transplanted to "elongation" tubes where they grow to between 2 to 3 cm in length. Next these elongated shoot tips are transplanted to container media for rooting and then used for planting in the indoor clone garden. The utilization of tissue cutting techniques and "micro-propagation" is now an integral part of most industrial *Eucalyptus* cloning programs in Brazil.

Harvesting of the "mini-hedges" for nursery propagation begins 20 to 30 days after planting the indoor clone bed. It is important that the harvesting of plant material occurs when sprouts reach a constant height from the bed in order to maintain a consistent level of juvenility, giving the clone garden a "mowed" appearance. Shoot tips of 2- to 3-cm lengths are harvested for use in cutting propagation. Each cutting has a single pair of leaves with 50% of the leaf blade removed. The cutting is planted into the standard container and follows the standard cutting propagation series of misting, shading, full sun, and well-monitored liquid fertilization. These shoot tip cuttings do not require basal hormone treatment to ensure rooting. In fact, even without IBA application, rooting generally increases by about 10% over stem section cuttings. There are also significant changes in planting stock quality. When using semi-hardwood cuttings, shoots and roots tended to initiate from lateral buds along the stem. When using the 2- to 3-cm shoot tip softwood cutting, the shoot tip forms the new apical meristem and the lead growing tip does not originate from the side of the plant. In addition, roots tend to grow straight down from the base of the cutting as opposed to growing from the side of the stem. The result is a faster-growing, more vigorous nursery stock.

The combination of tissue culture techniques and indoor hedging gardens results in a number of significant improvements in the production of planting stock: the time required for nursery production of planting stock is shortened by about 20%, rooting is increased by about 15%, planted stock is more uniform, and the plantations themselves are more vigorous and uniform, resulting in faster crown closure. Furthermore, not only is the indoor clonal mini-garden more economical to manage than larger outdoor gardens, more land is available for plantations because the land area previously used for the outdoor clonal garden is freed up (Ianelli and others 1996). The result is a highly proficient system that produces healthy, vigorous, genetically advanced planting stock for as little as $0.03 to 0.05 in USA currency.

Future Directions

Much of the recent progress in *Eucalyptus* clonal regeneration in Brazil has come about through cooperative efforts of universities and the forest industry. Several Brazilian universities have forestry research cooperatives similar to those found in the United States that routinely develop collaborative projects of mutual benefit. Clone based tree improvement and propagation has been one of the success stories of that collaboration. The Brazilian research community continues to place a high priority on plantation regeneration,

and there are several areas of on-going research to improve clonal *Eucalyptus* propagation. Some companies are interested in "closing the system" in their greenhouses and production areas. Because of environmental impact concerns, companies are searching for ways to circulate and reuse irrigation water. Aside from occasional pesticide application, there is heavy fertilization used during the propagation process, and a "closed system" would eliminate or greatly reduce the release of nitrogen, phosphorus, and other fertilizers into the environment. Other improvements may be made in the selection of soil medium used in the indoor mini-garden beds, looking for a well-aerated medium with good moisture availability that can be reused. Improved rootability of the unsterile cuttings used in the first stage of tissue culture can also be studied. The resolution of these and other problems will ensure that the Brazilian system will remain on the forefront of efficient *Eucalyptus* culture.

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Nursery Practices with Exotic Conifers in Patagonia, Argentina, and Some Reasons to Afforest the Region with these Species

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Key Words

Andean-Patagonian forest, steppe, afforestation, *Pinus ponderosa, Pinus contorta, Pseudotsuga menziesii*, mycorrhizae, bareroot nurseries

The southern portion of Argentina is called Patagonia, and is located between 37° and 55° south latitude. Across this region, there is a strong topographic and environmental gradient. Precipitation decreases from the western mountains towards the east and temperatures from north to south. These geographic gradients impose different structural patterns of soils and vegetation, as well as different patterns of ecosystem functioning (soil water dynamics, nutrient cycling, net primary production, etc). Forests dominate the more humid west Andean-Patagonian Region, predominantly on Andisols, in other words, volcanic soils (1,000 to 3,000 mm rainfall), while a steady transition from grasslands to scattered grass and shrub steppes on Aridisols may be found to the east (from 500 to 100 mm rainfall). In the transitional zone between both regions (500 to 1,000 mm), vegetation consists of shrub-grasses with scattered patches of *Austrocedrus chilensis* on xeric Mollisols, Hiceptisols or Alfisols (Mazzarino and others 1998). As an example of the striking decrease in precipitation, the mesic Valdivian rain forest and the xeric Patagonian steppe are sometimes separated by only 50 km (31 miles) (Montaña 1982).

In the western Andean-Patagonian forest, the young soils are derived from volcanic ash and generally exhibit adequate availability of cations and high water retention capacity. They also have a high capacity for P retention and organic matter stabilization, which can lead to both N and P deficiencies. In the steppe, soils are crystalline throughout the entire profile, with very low organic matter content, nitrogen content, and low water retention capacity. The main activity on the area is extensive sheep production, which is leading to severe problems of desertification. The transitional zone between the humid Andean Region and the arid steppe is a wide ecotone strip, representing the more important area for potential development of agriculture, cattle raising and forestry. Soils are mainly crystalline on the surface and amorphic (volcanic) in depth, with relative low contents of organic matter and N. During the last few years, research in this area has focused mainly on the introduction of exotic pastures, the improvement of native grasslands, afforestation with exotic pines, and agroforestry systems.

The first plantations with exotic conifers were established in 1940 and included the species *Pinus ponderosa*, *Pinus contorta* var. *latifolia* and *Pseudotsuga menziesii*. This initial program served to test the adaptations of these species to the Patagonian region. It was not until the 1970s that the government of Neuquén province began programs with the following objectives: 1) identify appropriate areas for forest plantations; 2) create nurseries; 3) begin intensive plantations; 4) develop human resources in both nursery and

plantation practices; and 5) develop wood industries once the plantations started producing. To accomplish all these objectives, Neuquén founded a forest corporation named Corporación Forestal Neuquina (CORFONE) in 1974.

Reasons to Afforest Patagonia

Adaptative and environmental reasons:

There are several environmental reasons for afforestation programs in Patagonia:

(i) Large areas of available land exist for afforestation.

(ii) The high annual growth increment of imported exotic species is often higher in Patagonia than in their original areas.

(iii) Watershed protection could result, especially in areas of steep relief where the erosion risk is high.

(iv) Eroded lands used in the past for intensive animal breeding could be restored.

(v) The Andean-Patagonian forests, which represent one of the few reserves of unaltered temperate forests in the world over extended areas, could be protected. This is assuming that timber provided by exotic conifers would diminish the pressure to cut these forests and thereby protect their biodiversity (Schlichter and Laclau 1998).

Economic reasons

There are also several economic reasons to undertake these afforestation programs:

(i) There would be a diversification of productive activities.

(ii) The initial investment required is lower than international values.

(iii) Its strategic geographic location allows access to markets on both the Atlantic and Pacific.

(iv) There are State and Federal forestry promotion policies that allow these comparative advantages to become competitive (Diaz 1997).

Nursery Practices

Bareroot production is the most extensive practice in Patagonian nurseries. Presently, *Pinus ponderosa* is the most common species produced, followed by *Pseudotsuga menziesii* and lately *Pinus jeffreyii.* Initially most seeds were imported from the states of Oregon, Washington, and California in the United States. Recently, a number of plantations from different seed sources growing at different latitudes and under different environmental conditions have reached their reproductive maturity. Consequently, intensive cone collection programs and seed processing plants have rapidly developed in the region. This seed collection has drastically reduced the costs for the nurseries. The use of seeds from regional plantations insures the reproduction of adapted ecotypes. However, attention must be paid to avoid abuse of this practice, which might result in the reduction of the genetic variation of the exotic forests.

Generally, cultivation practices (in other words, sowing, transplanting, and plant extraction) are not mechanized and, consequently, a high number of workers are employed in different months of the year. In the last few years, CORFONE has made serious efforts to improve the seedling quality and outplanting performance. There have been important advances in the irrigation, fertilization, and root management programs. Several outplanting trials have been installed across the different planting sites to determine the target seedling for each site.

Mycorrhizal inoculation is one important concern to consider as new tree species are being introduced. Between other mycorrhizae benefits, the enhanced uptake of P would be relevant in volcanic soils where plant P availability is low and therefore a limiting nutrient. Some of the species used for inoculation trials in CORFONE nurseries have been *Laccaria lacata* (Scop. Ex Fr.), *Hebeloma crustuliniforme* (Bull. ex Saint-Amis), *Telephora terrestris* (Ehrh.) Fr., *Pisolithus tinctorius* (Pers.) (Peredo and others 1989) and different species of the genus *Rhizopogon.* Presently, a common ectomycorrhiza found in Patagonian nurseries is *Rhizopogon* sp.

Intensive foliar analysis of *Pinus ponderosa, P. jeffreyii* and *Pseudotsuga menziesii* seedlings have been carried out since 1998 in two nurseries from Neuquén and Chubut provinces (CORFONE and INTA Las Golondrinas, respectively). The macronutrients analyzed were mainly nitrogen, phosphorus and potassium. Future plans will include the analysis of remaining macro and micronutrients. In the CORFONE nursery, *Pinus ponderosa* and *P. jeffreyi* seedlings, growing in crystalline soils under intensive irrigation and

receiving synthetic fertilizers, showed that foliar K was the main limiting nutrient for dry biomass yields (Buamscha and others 1999). In the INTA nursery, *P. ponderosa* and *Pseudotsuga menziesii* seedlings, growing in volcanic soils in rotations with Vicia and barley as green amendments, and without synthetic fertilizer applications showed: 1) very high N contents; 2) unbalanced P/N and K/N ratios; and 3) deficiencies of both P and K (compared with target values recommended for conifers in Chile and the Northern Hemisphere) (Basil and others 2000). There is still a need for research to determine the optimum nutritional levels for each species, especially for those growing in volcanic soils.

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Slash x Honduras Caribbean Pine Hybrids: An Overview of Nursery Production Systems Southeast Queensland, Australia

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Key Words

Container nursery, bareroot nursery, seedling production, vegetative propagation, clonal propagation, rooted cuttings, hedge management, controlled pollination

The Queensland Department of Primary Industries (DPI) Forestry has a requirement to produce 4.5 million trees per year for its plantation production program. This stock is raised at DPI Forestry nurseries in the southeast and far north of Queensland. To improve the productivity of its plantation estate, DPI Forestry has invested significant resources in the development of *Pinus elliottii* var. *elliottii* x. *caribaea* var. *hondurensis* (PEE x PCH) F. and FZ hybrid families and clones as well as associated delivery systems, including extensive clonal testing and hedge multiplication programs. More recently, it has commenced small-scale trials to produce "micro-cuttings." Past and present production techniques, including open-root, containerized seedling and cutting systems, and approaches to hedge management are presented in this paper.

Pinus elliottii var. elliottii x. caribaea var. hondurensis Hybrid Seed Production

F. hybrid seed production commences with the PCH pollination of PEE monoclonal seed orchards established at Byfield in coastal central Queensland. Seeds can be produced using either controlled or mass pollination techniques.

On account of the very low seed set, controlled pollination is not suitable for large scale production of F. hybrid seed; costs may reach $800,000 per kilogram. It is, however, the preferred method for producing small quantities of improved seed for either research programs or the establishment of high-quality family hedge plants. Controlled pollination may also be an option for the operational production of FZ hybrid family seeds because a much higher seed set is likely. Although mass pollinated seeds can be produced at a lesser cost, care is required to ensure that the seed orchard is fully emasculated to avoid contamination. This risk of contamination has caused the DPI Forestry to cease production of mass pollinated F. hybrid seed.

Pinus elliottii var. elliottii x. caribaea var. hondurensis Hybrid Nursery Production

DPI Forestry has developed and refined a range of techniques for seedling and cutting production of PEE x PCH hybrids in open root and containerized systems. DPI Forestry currently produces 3.5 million containerized cuttings per year. Previously, all stock was produced in an open-root nursery. This paper will review the two major nursery delivery systems:

1. Seedling production by seeding directly into containers or open root beds.
2. Cutting production following the establishment of seedling (or cutting) hedges

that are manipulated to produce shoots for vegetative production.

Depending on program requirements, seedlings can be produced either in containers or as open-root plants. Queensland has an optimum planting window from January to July and planting opportunities from October onwards, pending rainstorms, which previously allowed DPI Forestry to utilize both container and open-root systems to satisfy field requirements. The more robust container stock was used for summer planting to avoid the less desirable field conditions, and open-root plants were used for planting during the cooler and milder months. The split systems allowed for maximum utilization of hedge production. In order to extend the potential planting season and minimize possible outplanting risks, DPI Forestry has recently moved towards a fully containerized planting program. Experiences with both container and open-root production systems in the Queensland nursery are reviewed in this paper.

CONTAINER SEEDLINGS

Production

Container hybrid seedling production has a growing cycle of five to six months. Sowing is usually completed in August, and plants are available for planting in January or February. Seed is sown directly into containers using a precision sower. Following sowing, containers are placed into full sunlight and the newly sown containers are monitored for soil moisture three to four times a day. Possible bird damage is controlled by either placing meshing over trays or decoy feeding. Next, germination occurs at approximately two weeks and continues until week four. Finally, at week six germinants are ready for thinning or dibbling.

Irrigation

Irrigation utilizes a boom spray or fixed irrigation system. All of the water is sterilized by a chlorine gas injection system and application rates are monitored on a regular basis to match climatic conditions. Typically irrigation is required three times a day during the summer and is reduced to once a day during the winter months. Size and condition of stock will also effect water needs.

Containers

The most commonly used and preferred container type is the locally developed Queensland Native Tube (QNT) pot (currently manufactured by Statewide Nursery Supplies). The QNT pot (Table 1) was developed in an effort to improve root system structure and management. Its features include:

- Root ribbing to reduce root circling.
- An open base to facilitate air root pruning.
- A long container length to allow the root's core to be planted deeper into field soils.
- Containers to fit into holding trays, improving handling efficiency from the nursery to the field.
- Trays to provide optimum growing densities.
- Removable pots to allow for sorting during the growing cycle and to ease detubing while planting.
- Containers that are recyclable and will last up to ten years.
- Containers that can be steam sterilized.

Table 1. Container Specifications for Queensland Native Tube.

Container Dimensions	Tray Dimensions
Height: 12.5 cm	Size: 36 x 61 cm
Diameter: 5.0 cm	Cavities/tray: 40
Volume: 220.0 cc	Density: ~180 lm2

Potting Mix

A range of potting mixes are suitable for the production of hybrid pine seedlings and cuttings. The preferred potting mix for both seedlings and cuttings is either 50% perlite and 50% pine bark peat (manufactured peat from pine bark), or a blend of pine bark and pine bark peat. Osmocote provides the chief source of nutrients for the life of the crop. Potting mix is prepared in advance using either a small end loader or in a customized mixer filling machine.

CONTAINER CUTTINGS

Production

Container cuttings are normally set during June and July, October and November, and January and February. These split settings allow for

maximum utilization of available shoots from the hedges. Production of container cuttings is typically a ten to twelve month crop. Currently, 70% to 80% of shoots set will meet planting specifications. The growing environment for container stock features the following conditions:

- Site is protected from wind.
- Shade is provided by a 50% shadecloth.
- Sides are protected from direct sunlight.
- Airflow is good.
- Shade structures are drip-free.
- Temperature does not exceed 35 °C for extended periods.
- Site is free of weeds, algae growth, and molds.
- All irrigation water is chlorinated.

Following the preparation of the mix and filling of trays, the following procedures are adopted:

- Filled pots are placed on benches at waist height.
- Pots are irrigated to full capacity and physical checks are carried out to ensure high moisture levels are achieved.
- A dibble rack is used to ensure holes are centered and at a uniform depth of four centimeters. These trays are only sufficient for approximately thirty minutes of work because irrigation will fill in dibble holes.
- Cuttings are selected, checked to ensure compliance with specification, placed, and firmed with one action into the dibble hole.
- Trays, once they have been set, are drenched within ten minutes to reduce stress and assist with compaction.
- Newly set cuttings are protected from wind and sun by shading with a 50% shadecloth.
- Each tray is tagged, detailing the batch and date of setting.

Use of Rooting Hormones

The use of rooting hormones may be warranted for certain high value clones. However, at this stage their routine use is not recommended.

Irrigation and Conditioning

Cuttings are routinely irrigated for a minimum of two to five minutes each daylight hour. The amount of water applied depends on the type of sprinklers used. Sixteen to twenty weeks following the setting, a root assessment is carried out to determine strike rates. When a strike rate of 80% has been obtained, conditioning commences in the following order:

- Removing the shadecloth.
- Applying the slow-release fertilizer.
- Sorting stock - when height averages 12 cm, sorted stock is placed into a reduced irrigation conditioning area to harden, encourage mycorrhiza development, and allow root consolidation.
- Conditioning stock for a minimum period of one month prior to being dispatched into the field.
- Requiring a certain number of sortings because not all growth and rooting of cuttings will be uniform.

Insect and Disease Control

Fortunately, hybrid pines in Queensland have few serious insect and disease problems. Strict nursery hygiene is maintained throughout the growing process, including:

- Sterilization of potting mix.
- Use of chlorinated water.
- Sterilization of pots and trays before reuse.
- Chlorine sterilization of benches, floors, and greenhouse films between each crop cycle.

Weed Control

Nursery weed control is achieved by a number of techniques that include:

- Keeping nursery surroundings free of weed seeds by regularly spraying, maintaining a weedless environment under benches and in the immediate vicinity of container stock, and regular slashing and mowing of surrounding areas.
- Removing germinating weeds from pots as soon as possible.
- Testing growing media prior to use in order to ensure that it is weedless.

Open Root Production

Sowing

Sowing during August is performed using a Summit tractor-mounted 8-drill sower, which combines a vacuum drum sower, bed former, and

compacter/roller system, making the sowing a one-pass operation.

Setting

Following soil preparation, beds are formed using a Summit Sowing machine that forms the beds to a height of 10 cm and marks the setting drills. Irrigation is installed at least one full day prior to the commencement of setting to ensure maximum soil moisture is obtained. A pre-emergent herbicide application is applied just prior to setting.

Setting is carried out utilizing four-wheeled carts with seating adjusted to avoid excessive bending.

Setting is performed as follows:

- Cuttings are collected from the hedge production site and placed into cold storage.
- Cuttings are placed into wet hessianed-lined plastic crates that are drenched with water every ten minutes during collection, then drenched four times per day during cold storage.
- Shoots are placed into predrilled holes. With one action, shoots are pushed vertically to a depth of 4 cm and gently firmed around the base.
- Cloche frames covered with a shadecloth are installed immediately behind the setting operation.
- Irrigation is applied continuously during and after the setting operation for five minutes every hour during daylight hours.
- An application of Goal (*oxyfluorfen*) is applied within one week of setting.
- Shoots generally take approximately sixteen weeks to strike roots.
- A visual assessment of rooting is performed weekly after the eleventh week. When 90% rooting has been obtained, a manual root assessment is carried out to confirm rooting, and shade covers are removed.
- Slow-release fertilizer is applied by a tractor-mounted applicator.
- Irrigation is reduced.
- Operations from this point are similar to those for open-root seedlings.

Irrigation

Seedlings

After sowing it is necessary to maintain good soil moisture to assist with germination. Irrigation is required three times per day for ten to twenty minutes. A twenty-minute watering applies the equivalent of 1.5 mm of rain. Windy conditions require more frequent irrigation to ensure that the seeds will not be exposed or dry out.

Germination occurs at two weeks and is normally completed by the fourth week. Irrigation can then be reduced to two waterings per day. Windy conditions following germination require close monitoring of the soil moisture, taking into consideration the time it takes to fully irrigate the total sown area. Sand blasting of young, vulnerable shoots can result in large seedling losses and the multistemming of future stock due to tip damage or loss caused by sand particles.

Cuttings

Cuttings require constant irrigation, from the time of collection until rooting sixteen to twenty weeks later. They are so susceptible to drying out that constant attention is required to ensure that the cutting site retains near maximum moisture levels. Irrigation should be the equivalent of 6 mm of rainfall per day.

Weed Control

Seedlings

Pre-emergent herbicides Dacthal (*chlorthal dimethyl*) and Agaprop (*propazine*) are applied following seeding as well as at six to eight weeks. These applications will hold weed growth until mid-November, depending on intensity of rainfall.

From November, the main weed species are grasses controlled by the overtop spraying of a selective herbicide (Fusilade)(Fluazifop *p-butyl*). Until lifting ends in April, re-application may be required every six to eight weeks for grass control purposes. Some spot spraying, using a knockdown herbicide, might be used to control any resistant weed species.

Cuttings

Following the bed-forming operation and just prior to setting, a mixture of Dacthal and Agaprop is applied. Within one month of setting, an application of Goal is applied. Prior experience suggests that this combination gives excellent weed control for periods of up to twelve weeks,

despite the intensive watering program. Applications of Fusilade may be required to control any grass germination.

Root Pruning

All open-root seedling and cutting stock receive a number of root pruning treatments. Root pruning is an important tool in managing root development and it assists with the physiological conditioning of planting stock as well as the height control. Root pruning aids in the development of a strong, compact, and fibrous root system and it improves lateral root development. It consists of three distinct operations: reciprocating root pruning, lateral pruning, and bar wrenching.

Reciprocating Root Prune

A machine utilizing a sharp, reciprocating blade undercuts the open-root bed severing the taproots at a preset depth. The first root prune is carried out when seedlings/cuttings average 15 cm in height (January), and is continued every four weeks until April.

Lateral Pruning

Lateral pruning, to prune and enhance lateral root development, commences one week following the first root prune. It effectively prunes lateral roots growing across beds.

Bar Wrenching

Bar wrenching is the final tool used in the plant's conditioning process. The large, flat blade that is pulled under the nursery beds at a depth of 15 to 18 cm causes the soil surface to crack and subsoil aeration. This induces a further drought hardening response.

Topping

Topping by a tractor dasher may be required to control height growth. Care is required to ensure that only topping of soft new growth occurs, because topping too low into the woody tissue will result in multi-stemming.

Topping not only reduces and holds stock at a plantable height but it also induces diameter growth and uniform plant height.

Nutrition

Fertilizer additions are aimed to produce optimum growth and maintain the health and vigor of planting stock. Plant growth is carefully monitored during March and April in order to prevent excess fertilization, which will compromise the plant conditioning process. The aim at this stage is to monitor foliage color and plant conditioning and to also fertilize accordingly. Soil fertility is monitored annually, and applications are amended as required.

Original fertilizer prescriptions for open root cuttings relied on weekly foliar applications of NPK fertilizer. Problems were soon identified, and despite bi-weekly doses and different formulations, it was difficult to maintain optimum nutritional levels. It appeared that rooted cuttings do not have the ability to take up as much of the available nutrients as do seedlings, but respond well to slow-release forms that are available for longer durations. To overcome this problem, NPK is applied in a slow-release form once shade covers are removed. Currently, Osmocote® is applied for three to four months as an over-top dressing.

Lifting

Plants are ready for planting by April. It is expected that 90% of seedling stock and 65% of cuttings will meet planting specifications. Following sufficient rainfall, stock is lifted from the open-root beds. It is then packaged, cold stored, and transported to the field within several days. The lifting process is as follows:

- Beds for lifting are irrigated the day before lifting begins.
- A Fobro Lifter Shaker machine is used to lift seedlings from the open root beds. The lifting process removes plants from the beds, shakes soil from the roots, and places the plants in rows on the bed surface.
- Plants are packed into plastic crates and transported to a packing shed.
- Plants are sorted, culled, root pruned to 15 cm, root dipped, and packaged into plastic crates. Each crate holds 350 to 400 seedlings.
- Plastic crates are stacked onto pallets and stored under refrigeration at 2 °C and 95% humidity until needed; usually one to two days.

During this process it is important to minimize plant exposure to ensure maximum field survival following planting. This is done by strict quality control procedures that are closely monitored by a checklist system.

NURSERY AND AFFORESTATION PRACTICES IN INNER MONGOLIA, CHINA

RICHARD W. TINUS

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Tinus, R.W. 2002. Nursery and Afforestation Practices in Inner Mongolia, China. In: Dumroese, R.K.; Riley, L.E.; Landis, T.D., technical coordinators. National Proceedings: Forest and Conservation Nursery Associations—1999, 2000, and 2001. Proceedings RMRS-P-24. Ogden, UT: USDA Forest Service, Rocky Mountain Research Station: 177-182. Available at: http://www.fcnanet.org/proceedings/2000/tinus.pdf

Key Words

Bareroot nursery, container nursery, overgrazing, cultivation, vegetative propagation, poplar, windbreaks

In mid-October 1999, I visited Inner Mongolia at the request of the Forestry and Agriculture Organization to evaluate nursery practices and afforestation programs designed to protect the soil and provide wood products. Inner Mongolia is a narrow region of northern China immediately south and east of the country of Mongolia. It stretches from east to west about 2,000 km, equivalent to the distance from Minnesota to western Wyoming. The predominant native vegetation type is grassland; existing forests are all man-made. I was headquartered in the town of Tongliao, near the eastern border of Inner Mongolia on the 44th parallel north latitude. This location has a climate similar to central South Dakota. Precipitation is about 400 mm per year, concentrated during the growing season. Winters are cold and dry. Further to the east is the region of Manchuria that has higher precipitation and is largely forested. Many of the trees being tested for use in Inner Mongolia are native to Manchuria. At the far western end of Inner Mongolia is the Gobi Desert, with rainfall less than 100 mm per year. There is great concern regarding the rate of expansion of this desert in recent history.

The vicinity around Tongliao is heavily farmed, as is most of eastern Inner Mongolia, and this has resulted in major soil conservation problems. Loss of soil from wind and water erosion and loss of organic matter and fertility from intensive crop removal is widespread. Erosion is a problem because fields are usually without windbreaks and plowed to the edge of unprotected drainages (Figure 1). Extremely low levels of soil organic matter and fertility are common because of the high demand for plant materials for food, fodder, and fuel. For example, the aboveground portions of corn plants are harvested for human and cattle consumption, while the base of the stalk and roots are removed from the fields for home heating fuel. Cover cropping and fertilizer application to add organic matter and nutrients are not practiced.

Lowlands not suitable for cultivation are used for pasture. Pasture soils commonly have a very high percentage of sand and become shifting dunes with over-grazing (Figure 2). Some sand dunes have been planted with trees to stabilize the soil and reduce surface wind speeds, but with continued grazing and removal of lower tree branches for fuel and household products, these plantations are often rendered ineffective.

Lands historically reserved for trees are the hill tops (Figure 1). Scots pine (*Pinus sylvestris* L.) and Japanese larch (*Larix* sp.) are the predominant species. The wood is harvested for fuel and furniture. Homes are constructed of bricks or mud blocks due to the scarcity of wood. Opportunities for afforestation under these conditions are great. One success story is clonal poplar culture.

POPLAR CULTURE

Nurseries, such as in Tongyu, maintain stool blocks of local genotypes for vegetative reproduction. Poplar shoots are trained to one stem per rootstock, and by autumn, the stems are 4 to 5 m tall and 5 to 7 cm in diameter. These are harvested after leaf fall to produce poles 1.4 m long. After all branches are removed, the cuttings are fall-planted with only two buds above ground in holes drilled by auger (Figure 3). Because the

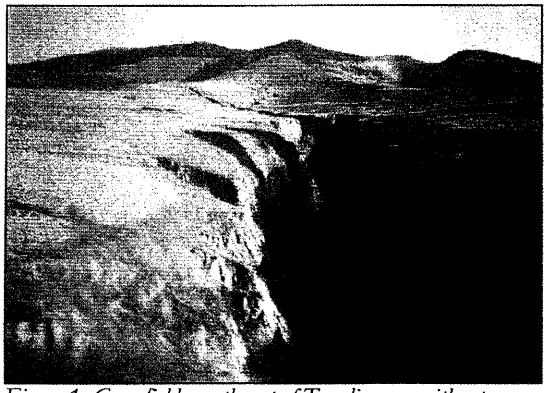


Figure 1. Corn fields southwest of Tongliao are without windbreaks and abut unprotected drainages. The gully is about 60 m deep at the level of the stream, visible behind the partially illuminated poplar. Scots pine from Manchurian sources, and Japanese larch are planted on the upland rolling hills.

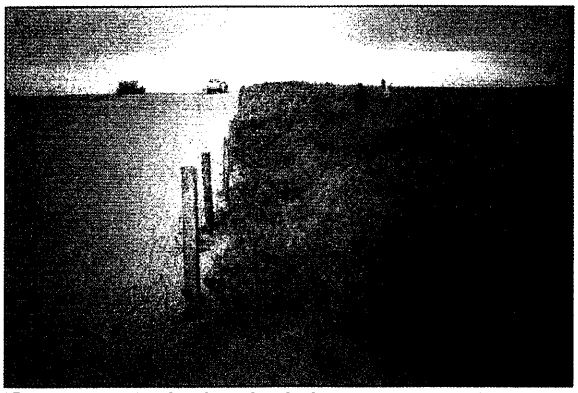


Figure 2. Lowland soils with a high percentage of sand are not suitable for cultivation and can become shifting dunes with overgrazing. Land to the right has been protected from grazing with fencing.



Figure 3. A poplar cutting windbreak being installed in a field of harvested sunflowers. The cuttings are 1.4 m long and 5 to 7 cm in diameter and are planted a few meters apart with only 2 buds above ground. (Closely spaced stalks in the foreground are sunflowers.) The tractor belongs to the poplar planter rather than to the individual farmer.



Figure 4. An eight-year-old windbreak of poplars (recently thinned) and Scots pines. Poplars are 12 m tall and 20 cm in diameter. The forest established on the hilltop in the background is of Scots pine and larch.

soil profile is almost entirely fine sand, this technique works well for establishing the poplar cuttings. Irrigation is not needed.

About 10% of farms have windbreaks. Rows of poplars are often planted adjacent to rows of Scots pine (Figure 4). Poplars after eight growing seasons in the field are 12 m tall and 20 cm in diameter. Commercial thinning is common once poplar windbreak trees reach this size.

One problem with the poplar culture to date is that most all the trees planted represent just two clones. Since this is a genetic risk, a research program is devoted to finding additional clones that will do well. Provenance plantings typically contain about 40 clones, and though only about10 years old, have quite a number of clones performing well. Genetic diversification should be possible in the near future.

An additional difficulty associated with poplar windbreaks is the practice of pruning up the branches as high as can be reached with a pole saw and a ladder (Figure 5). The farmers do this to harvest the one-year-old whips for fuel or to make baskets and other household items. Since the economy is resource poor, baskets and heat are perceived more valuable than wind reduction and erosion control. To relieve the harvesting pressure on windbreak biomass, block plantings of poplars are being established, as are large plantations of Scots pine.

SCOTS PINE PRODUCTION

A topic of great public interest is the relative performance of the local Scots pine plantations. Most agroforesters in this region of China are not traveled and have nothing to compare with their forests. The leader growth on the Scots pine indicates that they are growing well (Figure 6). The leaders are about 50 cm long without irrigation or fertilization. However, the closely spaced whorls at the base of the trees suggest the establishment period takes two to four years. Improved nursery and planting practices may speed establishment.

The largest Scots pine forest of the region is also the oldest at 40 years (Figure 7). It is currently being logged on an individual-tree basis for sanitation purposes to reduce a serious *Dothistroma pini* needle blight infection slowing tree growth. Though logging was not intended to begin this soon, the forest is producing a valuable commercial product (Figure 8). Because the trees are growing on 500 mm of rainfall, about half that of their native range, the forest cannot be expected to have the longevity or disease and insect resistance of Scots pine forests within the native range. Similar to trees on the Great Plains of North America, longevity is about half that of trees within the native range. This in no way suggests that the practice of establishing Scots pine forests for the future of Inner Mongolia should be abandoned. These forests are providing valuable services where no native species are present.

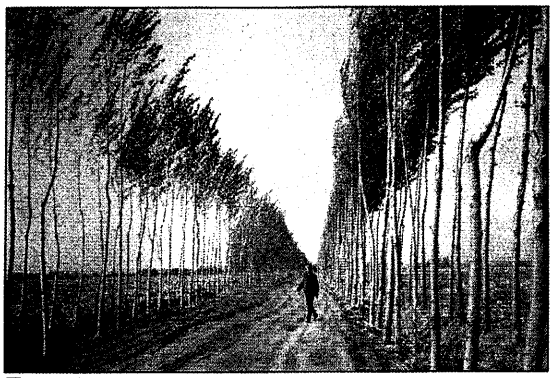


Figure 5. A farm windbreak of poplars along a rural road near Tongyu is pruned because the branches have greater value for fuel and the manufacture of household items than for wind and erosion reduction.



Figure 6. Examination of growth at a 10-year-old Scots pine provenance plantation near Zhanggutai by Professor Jiao Shuren, Senior Officer, State Forestry Administration. The trees are performing well. New leaders are about 50 cm long.



Figure 7. The largest Scots pine forest in Inner Mongolia is being logged after 40 years to remove trees infected with Dothistroma pini *needle blight.*



Figure 8. The 3 x 5 card next to 40-year-old Scots pine logs indicates typical tree diameters range from 15 to 35 cm when harvested from the oldest Scots pine forest in Inner Mongolia. Tree rings indicate good growth rates until the last few years when the trees became infected with Dothistroma pini *needle blight.*

BAREROOT CONIFER NURSERY PRACTICE

The Zhanggutai Nursery is the only such facility in northern China. It is a center for research, production, introduction of new species, and development of nursery techniques. Production is 600,000 bareroot seedlings, primarily 2+0 Scots pine. Soil pH is 6.5, which will be lowered to 5.5 over time by incorporating ground sulfur. Seeds are surface sterilized with potassium permanganate solution before sowing to reduce damping-off. Soil fumigation is yet to be tried. An irrigation system of moveable pipe and impact sprinklers is used. Artificial fertilizer is of limited availability and only applied to research beds. Good quality seedlings are being produced despite lacking some of the equipment commonly used in nursery practice. For example, sowing is accomplished with a new Italian-made precision seeder. However, seed cleaning equipment is unavailable to remove debris and hollow seeds from filled seeds prior to sowing. This results in germination of about 50% and non-uniform bed density (Figure 9).

Undercutting at 10 cm is done prior to root activity in the spring of the second year. This encourages production of fine roots close to the surface that will remain with the seedling when it is lifted. The root pruner is a stationary thin knife that does an adequate job, but would perform better if it were to reciprocate. Lateral root pruning is done with cutter wheels in early summer. A reciprocating root wrencher is used in late summer to stress the trees and induce bud set. Lifting is done in the spring by drawing a blade without movement under the seedlings (Figure 10). Scots pine seedlings (2+0) have good root growth in the fall when grown at a bed density of 200 seedlings per square meter (Figure 11). Seedlings are not lifted in the fall due to the absence of seedling storage facilities. However, overwintering in the ground at the nursery is difficult because of cold, dry, windy conditions, combined with unreliable snow cover. Burying the seedlings in sand is currently used to reduce desiccation, but is labor intensive and hard on the seedlings. Hoophouses over the beds, using white plastic with 70% shade, is an option being considered for use in conjunction with nursery windbreaks.

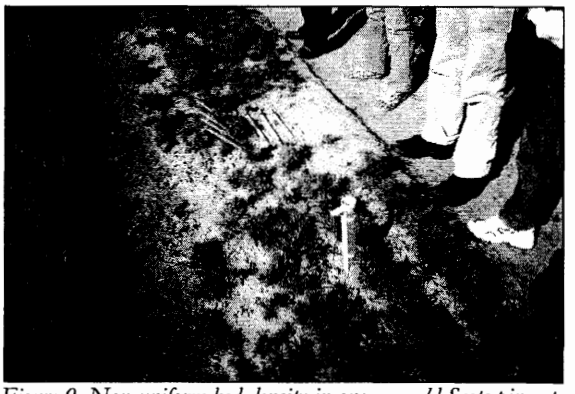


Figure 9. Non-uniform bed density in one-year-old Scots pine at the Zhanggutai Nursery resulted from sowing inadequately cleaned seed with a precision seeding machine.



Figure 10. The blade used to lift seedlings at the Zhanggutai Nursery.

CONTAINER NURSERY PRACTICE

Container production is in its infancy in Inner Mongolia and is severely limited by the greenhouse facilities available. The greenhouse at Naiman is representative of structures currently in use (Figure 12a). The 30 m x 8 m greenhouse faces southeast for maximum light intensity and has a freestanding brick wall to the north to keep out the cold. The bows of the house are of poplar. The covering is blue plastic held down in windy conditions by corn stalk mats rolled up to the peak of the roof when not in use. Since the blue color of the plastic filters out photosynthetically active radiation, sources of clear plastic are being sought. There is no means of artificial heating, and cooling is accomplished by cutting holes in the plastic.

Seeds are hand sown in April into plastic-lined paper pots containing a mix of sand and black humus. Containers are placed on the soil floor of the greenhouse. Irrigation water is available at a

hand pump well 75 m from the greenhouse (Figure 12b), and is transported to the plants in 10-L watering cans and applied by hand. Fertilizer is not used. Most seedlings are shipped and planted during the rainy season in June after a brief 20-day hardening period in the greenhouse with the plastic removed. Seedlings at the time of shipping are commonly small (12 cm tall, 2.5 mm stem diameter), actively growing, and suffering from the stresses of widely fluctuating greenhouse temperatures, often in excess of 40 °C. Survival is poor, and establishment can take a few years.

Some suggestions to improve seedling quality include: 1) use of a rigid wall container with multiple grooves and an egress hole at the bottom that is supported for air pruning; 2) use of a lighter media such as a fibrous peat mixed with vermiculite, perlite, or coarse (3 to 4 mm) sand, and slow release fertilizer; 3) use of mechanized irrigation to provide sufficient and uniform watering; 4) sowing earlier to allow more growing time and 40 days to harden; and 5) use of a vent system that is easy to open and close, and a thermohygrometer to monitor conditions.

OUTPLANTING PRACTICE

Establishment of tree plantations requires successful execution of a series of steps from seedling production, to site preparation and planting technique, to post-planting grazing and weed control. There are many young plantations where it is evident that great care was taken at each step. For example, protection is often elaborate (Figures 13a, 13b) with fences and moats to exclude cattle, and scalping in the immediate vicinity of the seedlings to reduce competition, while leaving weeds beyond a

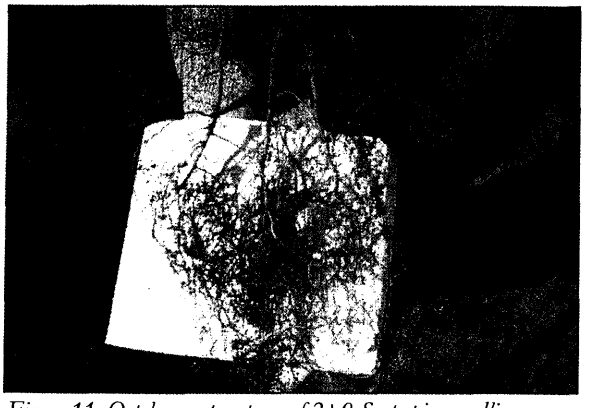


Figure 11. October root systems of 2+0 Scots pine seedlings pruned to 10 cm at the beginning of the second growing season at the Zhanggutai Nursery.

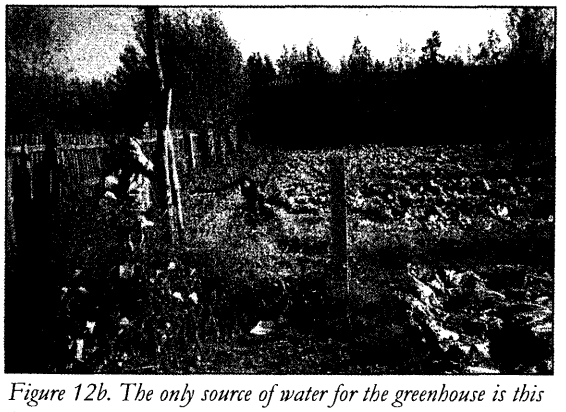


Figure 12b. The only source of water for the greenhouse is this hand pump well. Surrounding fields are of cabbage, a winter cover crop at the nursery.

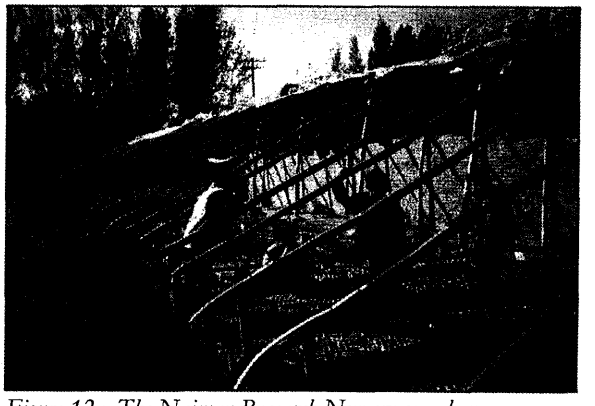


Figure 12a. The Naiman Research Nursery greenhouse. Seedlings have been shipped. The blue plastic skin is rolled up the roof in preparation for winter. Wu Aimin, Chief of the Division of Publicity, State Forestry Administration, crouched at left, films the tour.

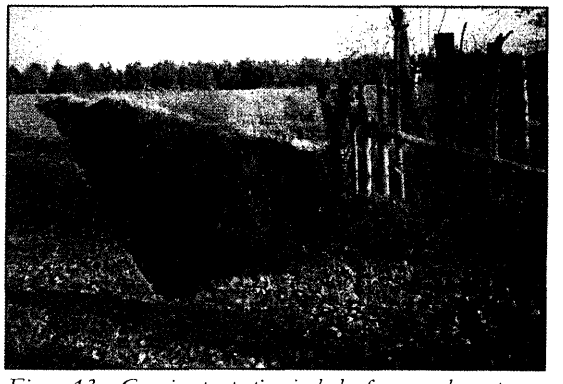


Figure 13a. Grazing protection includes fences and moats. Evidence of successful plantation establishment a generation ago is evident on the skyline.



Figure 13b. Scalping around the seedlings reduces competition while outlying weeds offer wind protection and soil stabilization.



Figure 14. A sparse 10-year old Scots pine plantation still experiencing mortality resulting from spiraling of roots during container production.

meter to provide wind protection. From a distance, areas like those in Figure 13 look like fields of weeds, but the surrounding healthy Scots pine forest plantings (background Figure13a) serve as a testimonial to the success of this approach.

When failures occur, a common cause of seedling mortality is improper planting affecting root form. 'J'- and 'U'-shaped root systems on bareroot seedlings, and balled, spiraled, and bagged root systems of polybag seedlings are found. For example, at a 10-year-old Scots pine plantation (Figure 14), trees were gradually and mysteriously dying while neighboring naturally established woody shrubs were thriving. The trees had been produced as 1.5 m balled stock. The roots developed spiraled and are now strangling the trees. Training new local tree producers and planters is an ongoing challenge here, as it is throughout forested regions.

PROVENANCE PLANTINGS OF ADDITIONAL SPECIES

Genotypes from the Great Plains of North America are being tested for suitability in Inner Mongolia. Jack pine (*Pinus banksiana* Lamb.) is performing comparably to the Scots pine in test outplantings. Ponderosa (*P. ponderosa* Laws.) and lodgepole (*P. contorta* Dougl.) pine genotypes are not doing well because the seed sources are from 52° north latitude in Canada. South Dakota sources, closer to the 44° north latitude of Inner Mongolia, will soon be planted. Performance should improve. Eastern redcedar (*Juniperus virginiana* L.) seedlings from South Dakota sources were planted a year ago. Many are already established and doing well. For greater drought resistance, Rocky Mountain juniper (*Juniperus scopulorum* Sarg.) will be added to the trials. *J. virginiana* is native from the east coast of North America to the middle of the Great Plains, representing a rainfall belt of 130 cm to 500 cm. *Juniperus scopulorum* grows west from there and is native to a rainfall belt of 60 cm to 350 cm. Careful selection of genotypes and expanding contacts with sister nurseries from similar climatic zones will enable diversification of forest plantings in Inner Mongolia.

NOTE FROM THE AUTHOR

I find visiting nurseries around the world very rewarding. It provides the opportunity to learn from the diversity of solutions to similar biological challenges involved in tree seedling production and establishment. I encourage you to participate in these exchanges.

GEORGE O. WHITE STATE PARK FOREST NURSERY—LICKING, MISSOURI

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Hoss, G. 2002. George O. White State Park Forest Nursery—Licking, Missouri. In: Dumroese, R.K.; Riley, L.E.; Landis, T.D., technical coordinators. National Proceedings: Forest and Conservation Nursery Associations—1999, 2000, and 2001. Proceedings RMRS-P-24. Ogden, UT: USDA Forest Service, Rocky Mountain Research Station: 183-186. Available at: http://www.fcnanet.org/proceedings/2000/hoss.pdf

Key Words

Bareroot seedlings, soil management, shrubs, native plants, wildlife

The George O. White State Forest Nursery is owned and operated by the Missouri Department of Conservation. Our agency is responsible for the management of the fish, forest, and wildlife resources of the state.

This paper will address the George O. White State Forest Nursery. It will discuss where we are, a little of our history, and our growing conditions. It will then demonstrate how we grow shrubs and small trees that Missouri landowners use for a variety of plantings.

Compared to many other nurseries presented at this conference, we might appear old-fashioned. We just take seeds, put them in the ground, and grow trees!

HISTORY OF GEORGE O. WHITE STATE FOREST NURSERY

The George O. White State Forest Nursery is located in south central Missouri, in growing zone 6. Statewide, we cover growing zones 5, 6, and 7. The site for our Nursery was chosen in the early 1930s by the U.S.D.A. Forest Service to primarily grow shortleaf pine (*Pinus echinata*) to reforest the new lands being obtained on newly created national forest land.

The nursery opened in 1935 as a Civilian Conservation Corps (CCC) Camp. At one time there were over 200 men living on site doing the work to run the nursery. There were barracks, a mess hall, and recreation facilities for the camp. World War II shut the CCC program and the nursery down. In fact, the irrigation system was dismantled and taken to a rubber plantation in California to help grow rubber for the war effort.

In 1945 the Forest Service reopened a small portion of the nursery. However, in 1947 both the land and buildings were leased to the Missouri Department of Conservation for twenty-five years. Since then, the facility has operated and greatly expanded. In the early 1970s, the Department assumed ownership of all the land and buildings that had previously belonged to the Forest Service.

During the 1950s and 60s, the nursery reached its peak when we distributed more than 10 million trees a year. But now, about four and a half to five million/year is typical.

We take orders from late November until May 1st. Order forms are sent to about 25,000 addresses each fall, and we typically receive 11,000 to 14,000 orders/year. We are now on the Internet and customers can place orders via our web page. Each order must be for a minimum of 25 trees of a species. Nearly all of our trees are shipped to the customers using USPS and UPS. Only a small percentage of our trees are delivered or picked up at the nursery.

SITE OF NURSERY

The site of our nursery was chosen in the 1930s to grow pine, and it is a relatively good site for that species.

Located in a narrow valley along a creek, our nursery is spread out over nearly 1.25 miles north to south and it is less than a 0.25 mile wide. The site is very flat with a maximum 1% slope.

Soil and Soil Management

While sand or sandy loam seems to be desirable for best nursery soil, this nursery is different. Ours is silty clay loam soil, mostly—heavy on the clay.

Since heavy clay soil dominates, wet soil at seeding time and lifting time creates problems. Our soil is slow to dry out, and compaction is also a problem. Hardpan has developed in many areas and we annually use a large dozer and deep subsoiling (to about 30 inches) to break the hardpan.

We try to idle at least one-third of our seedbed space annually. Traditionally, we used a cover crop of sorghum x sudan grass and disked or plowed under the residue. Part of our hardpan problem was the plowing. During this past summer (2000) we used Roundup Ready soybeans as our cover crop. It is more expensive, but allows us to do excellent weed control within our cover crop. The soybeans were much easier to disk into the soil than sorghum x sudan, and as a legume it will fix nitrogen. Our first attempt at using the soybeans looks very promising. The beans did great and our weed control was wonderful.

We do use methyl bromide, which is applied in September by a contractor. It works very well for us, and we have not yet tried any of the alternatives.

We have both permanent and temporary irrigation systems on the nursery. Both have their advantages and disadvantages. We water for temperature control as much as for watering the plants. We have three wells of over 1000 feet deep that bring us high pH water—very cold—but raises pH. We fertilize using ammonium sulfate, 21-0-0-24, to put some acid back in the soil.

Species

Initially shortleaf pine and a few other species were all that was grown. From 1960 through 1980 we were heavy into exotic trees and shrubs. Scotch pine and autumn-olive were two of our biggest sellers. We grew Nanking cherry, European black alder, autumn-olive, lilac, tartarian honeysuckle, mimosa, and some natives. But by the late 80s and early 90s, we phased out nearly all non-natives and we now grow mostly native trees and shrubs.

Approximately 60 species of trees and shrubs are now grown annually. This includes conifers (Missouri has only 2 native conifers), shortleaf pine, and eastern redcedar (*Juniperius virginiana*). But we also grow or purchase six other pine species—red, white, jack, Austrian, and French and Belgium Scotch pines. Our conifer sales amount to about 1 to 1.25 million a year, and shortleaf pine and white pine (*P. strobus*) are about 90% of this.

We grow about 35 species of hardwood trees which include thirteen species of oak (*Quercus*), with pin, bur, northern red, black, swamp white, and white the main oaks, black walnut (about 250,000 to 500,000 per year), and our native pecan (about 250,000 per year) are among our more popular hardwoods. We grow many other species including silver maple, sycamore, river birch, tulip poplar, bald cypress, sweetgum, green and white ash, and cottonwood.

Wildlife Shrubs

We grow 15 to 18 species of shrubs and small trees that are mainly for wildlife habitat improvement, wetland restoration, windbreaks, and erosion control.

Nearly all of the seed for all our shrubs are locally collected or bought from within 30 miles of our nursery. We clean, dry, and store all of this locally purchased seed.

We plant all our shrubs in gassed ground; most are planted using a seven-row LOVE seeder. All beds are mulched with sawdust to a depth of 0.25 to 2 inches, depending on species and time of year. All seedbeds are then covered with hydromulch to hold the sawdust in place from wind erosion.

Dogwood (*Cornus* spp.)

We grow three species of dogwood, occasionally four.

- Flowering dogwood—*Cornus florida*
- Roughleaf dogwood—*C. drummondii*
- Gray dogwood—*C. racemosa*

We handle all three species of dogwood the same. They are planted in late September or first week of October, at the latest. Since it is planted so early we rarely, if ever, have fresh seed to plant. We use dogwood that has been in freezer storage, and have had success with *Cornus* seed stored for over 12 years. We do nothing to the seed except take it out of freezer storage and plant it. However, one key thing we do with the dogwoods is keep the soil damp after seeding until winter.

We do not keep the ground soaked, but we do water it when needed. We clean all of our dogwoods using a Dibvig macerator.

Sumac (*Rhus* spp.)

We grow two, sometimes three, species of sumac:

- Fragrant (or Aromatic) sumac—*Rhus aromatica*
- Smooth sumac—*R. glabra*

We plant these very differently.

Aromatic

The seed is soaked for 45 minutes in hydro sulfuric acid (H_2SO_4), washed thoroughly with water, and then let dry. It is kept at cooler storage (34 °F) until planted, after October 15th and before October 30th. Planting before mid-October can cause problems. In the past, planting in early October risked receiving lots of rain and warm weather, resulting in this species germinating in early November. It was then killed several weeks later when hard freezes occurred. This seed ripens early in the summer and is purchased locally in June and July.

Smooth sumac

The seed is soaked for 60 minutes in hydro sulfuric acid. Unlike aromatic sumac, this species is not planted until mid to late May and the later in May the better. If planted too soon after the last frost they can grow very large (over five feet) by fall. Treatment has been soaking it in boiling water, but this is very slow and germination is not as good as an acid treatment.

Redbud (*Cercis canadensis*)

This species is also soaked in H_2SO_4, but for only 30 minutes. Like smooth sumac, it is also planted in the spring, usually May 1st to 15th, after the last killing frost. Planting any earlier could result in the species being frosted (and this species is very intolerant of frost), and it also gets too big if planted earlier. Because there has been some trouble getting redbud to harden off in fall or even leafing back out in late October, it is not watered in September or fertilized after mid or even early July. This is one of the few shrub species where we do buy our seed commercially, but we also collect and clean our own seed.

Blackberry (*Rubus* spp.)

Blackberry is sowed in the first week of July. This species seems to require a long period of warm then cold then warm weather to germinate in the following spring. To help get this species to flow properly through our seeder, the seed is mixed one to one by volume with sifted sawdust. It is sown very shallow and covered with sawdust. The seed can be acid treated, but it did not work well at this nursery, and the small seed size made it very difficult to work with in the acid. All seed is purchased at the nursery from locally picked berries and a macerator is used to clean the seed.

Wild plum (*Prunus* spp.)

There are seven or eight species of wild plum native to Missouri. All but one species is native to the county where our nursery is located. Wild plum is one of the easiest plants to grow. The seed is hand sown in early October and by mid April it is already six inches tall—way before many other seeds have yet to germinate. Late frosts don't faze it a bit. By summer's end, with little fertilizer and water, they are three to four feet tall. It is very popular for wildlife planting, and the fruit also makes a great jelly. Plum is a seed that stores very well, and really good seed crops occur only every three to five years. When there is a good seed crop, thousands of pounds—as much as we can get—are purchased to help get us through the lean years of poor seed crops. We clean the plum using our macerator.

Washington hawthorn (*Crataegus phaenpyrum*)

This is a low growing, small tree/shrub, and is a very good wildlife cover and food. The hawthorn is the Missouri state flower, and there are about 50 native hawthorn species in Missouri; Washington is one of the most widespread. Like dogwood, it is easy to grow and sowed early—late September to first part of October. This seed is watered if there is not much rain before winter. In the past, the seeds planted in late October have done poorly, demonstrating that this species needs a warm weather period before cold weather in order to germinate well the following spring.

Ninebark (*Physocarpus opulifolius*)

This small shrub grows very well on dry, gravelly creek bottoms and wet areas, but it is tolerant of a wide variety of sites. It is becoming widely used in wetland projects and for wildlife habitat, and is also good for stream side restoration. A large, matted root system forms in seedbeds. This small

seed is planted in mid-October, and it is very important to plant it at a shallow depth. As with blackberry, the seed is mixed at a one to one ratio by volume with sifted sawdust to aid in getting through the seed drill. The seed pods are then collected in August and allowed to dry in order to extract the seed.

Witch hazel (*Hamamelis vernalis*)

This shrub grows to about ten feet tall and gets bushy. The fruit is picked slightly green and put on screens to dry. The screens must be covered to protect the seed, which explodes out of the fruit. Even with the screen boxes covered, seeds can still be found 30 feet away. The seeds are sown in early to mid October with no other treatment. This is a slow growing seedling.

Red mulberry (*Morus rubra*)

This is a small tree and it can only grow up to 50 feet. It is planted solely for wildlife, and has very little timber value. It is planted in mid to late October. This seed is also small and mixed on a one to one ratio by volume with sifted sawdust. The fall sown seeds have growth rates of three to six feet in one year. But if planted in April, the seeds germinate slowly. Usually even the fall sown seed does not germinate until late April or early May.

Deciduous holly (*Ilex decidua*)

This grows on both wet and dry sites and averages 15 to 20 feet tall with a wide span. Red berries that grow on the female plant attract wildlife in the late winter. The seed is planted in September and lies dormant for 19 months; it then germinates in April. Nothing can break dormancy but time and it takes at least three years to become a deciduous holly.

Shrub lespedeza (*Lespedeza thunbergii*)

This is a native of Asia and is excellent for quail food and cover. It is sown in mid-May and great big seedlings appear in the fall. There is no inoculation or treatment of seeds.

Hazelnut (*Corylus americana*)

Also called American filbert, this seed is loved by squirrels and deer. The nuts have a leaf-like structure. Approximately 10,000 pounds of seed are purchased in the husk from local collectors. After drying and cleaning, this seed reduces to only 2,000 pounds. The drying process takes several months, and a macerator and hammer mill are used to clean the seed. However, it has been found that a brush drum seed cleaner does the best job. The acorn seed drill and fall plant are used in mid October and the seed is then collected in late August while it is still green.

Buckbrush (*Symphoricarpos orbiculatus*)

Approximately 20,000 of these plants are sold per year. It is planted at the same time (July) and manner (sifted sawdust) as we do blackberry. Likewise, it seems to do best if given three or four months of warm weather before the winter sets in.

Other Plants

A few other plants that we grow include: slender lespedeza (*Lespedeza virginica*), persimmon (*Diospyros virginiana*), Ohio buckeye (*Aesculus glabra*), serviceberry (*Amelanchier arborea*), smoketree (*Cotinus obovatus*), and dwarf hackberry (*Celtis tenuifolia*) along with three shrub willows (all cuttings—not seedlings).

Conclusion

The demand for shrubs by landowners of Missouri has not decreased. Shrubs are used on many projects—wetland, wildlife habitat plantings, windbreaks, erosion control. Over the last few years, over a million shrubs have been sold annually. In the future, the amount purchased and sold may cause an increase in the variety of shrubs that are grown in this nursery.

SEED ENHANCEMENT/UPGRADING TECHNIQUES: READ THE SEED

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Creasy, K.R. 2002. Seed Enhancement/Upgrading Techniques: Read the Seed. In: Dumroese, R.K.; Riley, L.E.; Landis, T.D., technical coordinators. National Proceedings: Forest and Conservation Nursery Associations—1999, 2000, and 2001. Proceedings RMRS-P-24. Ogden, UT: USDA Forest Service, Rocky Mountain Research Station: 187-195. Available at: http://www.fcnanet.org/proceedings/2000/creasy.pdf

Key Words

Seed processing, IDS, seed cleaning, PREVAC, seed quality, seed purity

To the nursery industry in Canada, seed enhancing and upgrading techniques have ever increasingly become and are now an integral part of their operations prior to greenhouse sowing. The terms "enhancing" and "upgrading" can be used interchangeably, but they essentially mean the same thing. It's the idea of improving the quality of initial processed seed, which can be accomplished in many ways. Our upgrading work encompasses a number of coniferous species, such as white, red, jack, and lodgepole pine, and white, black, Engelmann, and blue spruce.

Credit for the initial "operational Incubation, Drying, Separation (I.D.S.)" beginnings in Canada over and above the documented research goes to the former company of Western Tree Seeds of Blind Bay, British Columbia—Frank Barnard and Tom Hilman to be precise. These two gentlemen began with an idea and made it reality. Others have also had significant input, resulting in proving this technology to be a benefit for the nursery industry.

Water separation techniques applied to cleaned seeds, removing physically damaged seeds, heavy debris, light debris, and dead/empty/partially filled seeds are making notable improvements to seedlot vigor and germination capacity. Seeding efficiency and conservative utilization of the seeds are the most important and beneficial factors. When using water separation techniques, seed is more responsive when compared to air separation equipment. The upgrading techniques for this presentation center themselves by utilizing the combined effects of pressure vacuum (PREVAC®) and I.D.S. Important scientific principles and attention to detail for each of these is integral, and combined, these form the cornerstone for achieving successful results. Tracking moisture content—initially and throughout the processes—is essential and very interesting to follow. A picture is provided by this information as to what moisture levels are in the various stages of treatment.

It is very important to have a preset worksheet to record initial seedlot details as well as all pertinent and necessary information collected through all processing stages. Once treatment is completed, a wonderful snapshot is created giving an excellent reference of the seedlot dynamics and how the results were derived. Similar situations with other seedlots can be determined by comparison as to whether the results are favourable or not or even as an antidote to describe something unique.

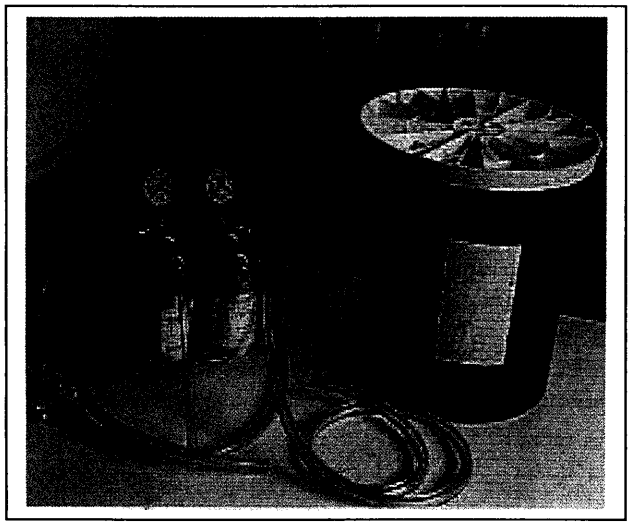
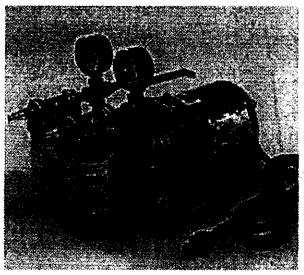


Figure 1. Prevac Unit

Vacuum Pressure Pump, Gast*

This pump is readily mounted and produces steady, quiet, pulseless air delivery. Ideal for intermittent service alternately. The pump rotor is mounted on the motor shaft. Composition vanes take up their own wear automatically. Self-adjusting shaft seals prevent oil leakage. The motor is a 1/3 hp ball bearing-type, with internal thermal-protector, fan cooled.



Free Air Displacement:	4.5 cfm
Ultimate Vacuum:	26" Hg
Pressure:	15 psi
Electrical:	115V, 60Hz
Weight:	15 kg (33 lbs.)

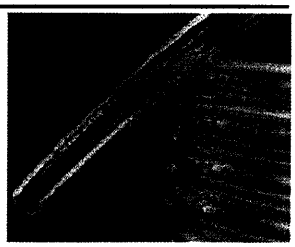
CSA listed.

Figure 2. Catalogue information

290 PUR Tubing, Ether-Grade, NALGENE*

For high-purity work, pressure applications, metering pumps, degreasing lines, acid lines, gas and oil lines, slurry transfer, solids and granular transfer.

Contains no plasticizers and low level of extractables. Clear, flexible clean polyurethane tubing has excellent chemical resistance. Offers good resistance to hydrolytic degradation. Often used with distilled, deionized, demineralized or reverse-osmosis treated water. Durometer hardness: Shore A, 75. Operating temperature range: -56° to 80°C (70° to 175°F). Not autoclavable, but can be gas sterilized. Imprinted every 12 inches with "NALGENE 290 PUR" and one-foot markings. Available in 50' coil lengths.



Vacuum Chambers, NALGENE*

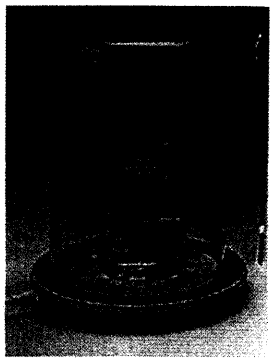
Vacuum chamber consists of transparent jar, neoprene gasket and vacuum plate with adapter for ¼" I.D. tubing.

Vacuum Chamber, **54929-051**, has a polycarbonate (PC) jar and white polypropylene plate. It is intended only for applications using non-aggressive chemicals, e.g., student demonstrations of vacuum procedures. Vacuum Chambers, **54929-062** and **-084**, have pale amber polyetherimide (PEI) jars with excellent chemical resistance to acids, bases, aliphatic alcohols and hydrocarbons and saturated halogenated hydrocarbons; plates are white polycarbonate.

Replacement parts are available. Polyetherimide vacuum jars are chemically-resistant and have an amber cast. Vacuum plates, for use with jars or glass bell jars up to 12½" in diameter, are supplied with 3/32" thick gaskets. Tubing adapter that fits ¼" I.D. tubing is conveniently located on rim of plate. Replacement gaskets are available.

Note: Do not autoclave these jars when used for a vacuum service. Do not use with unsaturated halogenated hydrocarbons.

Ordering Information: Vacuum chambers include jar, gasket and plate.



54929-051

Figure 3, 4. Catalogue information

PREVAC®

The principle for PREVAC® is that vacuum pressure is created within a pressure vessel containing the appropriate amount of seeds and water: "air and airspace are replaced by water." (Figures 1 through 4.) Damaged seeds (whether cracked, abraded, or chipped) and heavy debris therefore become heavier than the water and sink. Species tolerance to vacuum pressures and the amount of time needed must first be established before the proper protocol can be set for operational routines. With some species—for example, black spruce—modified Glycerin based ($C_3H_3O_2$) solutions, may need to be used to achieve a proper sink/float pattern. Seed density can improperly represent damaged seed and cause sound, healthy seeds to end up as part of the sunken fraction.

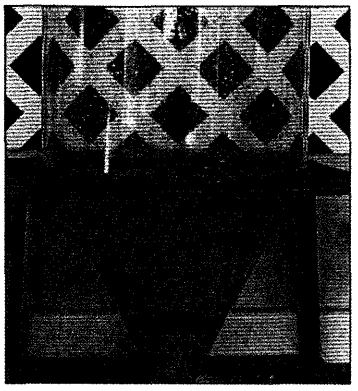


Figure 5. Cone

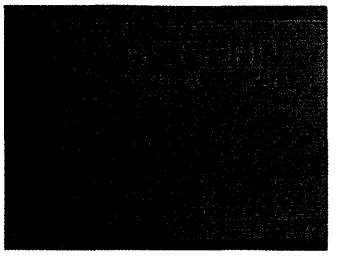


Figure 6. Glycerine Label



Figure 7. Spin Dryer

A transparent "cone" constructed from acrylic and lexan material with a bottom valve is the unit used for separating the good and damaged portion of the seedlot after the pressure treatment has been applied. Remember—the floating seeds in this stage represent the good fraction; the sunken is the removed or discarded fraction. In order to achieve the best separation, the floating seeds will need careful, frequent stirring and poking with a small dowel stir stick while in the "cone" to allow the damaged seeds and debris to move through the seed mass and settle to the bottom.

To collect the damaged seed fraction, a nylon mesh bag is placed over the valve outlet and opened. The water is drained until the good seed fraction just reaches the valve inlet and then the valve is closed quickly. Water is refilled and the process repeated; it may be necessary to repeat this step a couple of times in order to gain the desired result. Initially, the water may be very murky due to resin dust being removed from the seed, so a close eye must be kept as to where the base of the good fraction is and to be sure that no funneling is occurring within the cone as water is being drained. Once finished, the good fraction is also collected into a nylon mesh bag. Catching the seeds in separate mesh bags then allows the water to be spun from the seed using a "spin dryer" unit (Figure 7). To determine if the process is done well, tip the mesh bag from side to side. The good seeds will have a nice rustling sound as the seeds move within the bag. Some floating debris may be remain, but this is something that is of little concern, as it will come off with the floating fraction through the I.D.S. treatment. But be sure to watch that it does not become a pathogenic source through the next stage. Spin the seeds until the water draining out slows to just a slight drip. To prevent equipment damage or premature wear, ensure that the centrifuge is balanced while spinning.

Collecting a sample for moisture testing after this separation is completed is very necessary for both the good and removed fractions for two reasons: 1) to draw a comparison of the actual percentage of seed/debris removed from the seedlot through the dry weight calculation; and 2) calculating the dry weight of the good fraction as this is the basis for determining moisture content right up to the point of separation and is a very important primary function. It is always interesting to note the difference in moisture content between the two fractions. The good fraction will range in moisture content in an area of 12% to 15%, while the removed fraction will range broadly from a low of 16% to a high of about 30%. Species types and certainly individual seedlots have interesting resultant moisture contents.

PREVAC® Equipment: Build Your Own

The supplier of PREVAC® equipment is VWR Canlab, whose Internet address is: www.vwrcanlab.com, or telephone: 1-800-932-5000

Equipment Details:

- Gast Pressure/Vacuum Pump—Model #0323V4AG582DX; Cat. No. 54907-057
- Vacuum Chambers, Nalgene—8 3/4-inch outside diameter by 10=inch height; Cat. No. 54929-62

- 12-inch outside diameter by 12-inch height; Cat. No. 54929-084
- 290 PUR Tubing, Ether-Grade, Nalgene—1/4-inch inside diameter by 3/8-inch outside diameter; 1/16-inch wall thickness; Cat. No. 63014-228

The separation cone and stand are items built; these could be constructed very simply if you are handy with design and fabrication work.

Protocols By Species

Black Spruce PREVAC® and Purity Enhancement Protocol Steps

PREVAC®

- Pressure vacuum, letting vacuum pump reach a maximum vacuum pressure of 25 inches of mercury.
- Approximate run-up time is about ten seconds.
- Remove seeds from vacuum chamber by pouring seeds into cone, partially filled with water.
- Stir, drain, and collect the seed fractions into a mesh bag. Remove excess surface water using the spin dryer.

OR

- Pressure vacuum as above, remove seeds from vacuum chamber by pouring seeds into cone, partially filled with water and collect the sunken portion into a separate mesh bag from that of the floating fraction.
- Remove excess surface water using the spin dryer. Modified solution separation will only be used on the sunken fraction to recover lost seeds and can be simply done by adding glycerin to the water until the desired seed float is observed. Experience can be the best teacher.

Separation

- Prepare a glycerin ($C_3H_8O_3$) solution with a specific gravity of 1.060. Check first to ensure that this is the correct specific gravity required by first treating a couple of 100 seed reps. The test separation is evaluated by germination test information received. This specific gravity is generally acceptable for black spruce seeds with 14% to 15% moisture, but expect seedlot variations.
- Pour seed into the mixed solution contained in separation cone.
- Stir to mix in well and allow to settle over the next few minutes.
- Resins, stones, other heavy debris, and cracked and damaged seeds will sink to the bottom.
- Remove debris, seeds, and particulate material collected in the bottom of the cone and those seeds suspended below the main floating fraction. Use a catchment container for glycerin liquid as the solution can be stored and reused.
- Rinse both fractions well in cold running water and again remove excess surface water in the spin dryer. This floating seed fraction can now be combined with the initial floating fraction.
- Separation is complete, and the next stages of upgrading treatments can now proceed.

Variations in the specific gravity of the solution are usually due to moisture content.

Some of these are:

Specific Gravity	Moisture Content (Percent)
1.033	Seven to eight
1.060	Fourteen to fifteen
1.100	Twenty-six and one tenth—large size fraction
1.115	Twenty-five and nine tenths—small size fraction

PREVAC® and Purity Enhancement Procedure For Other Species

Jack Pine

PREVAC®—Pressure vacuum, letting vacuum pump reach a maximum vacuum pressure of 27 inches of mercury for one minute, inclusive of run-up to pressure.

Lodgepole Pine

PREVAC®—Pressure vacuum, letting vacuum pump reach a maximum vacuum pressure of 15 inches of mercury for thirty seconds to one minute, inclusive of run-up to pressure.

White Pine

PREVAC®—Pressure vacuum, letting vacuum pump reach a maximum vacuum pressure of 27 inches of mercury for thirty seconds, inclusive of run-up to pressure.

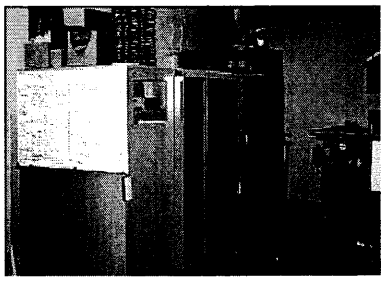


Figure 8. Misting cabinet with vapourizers

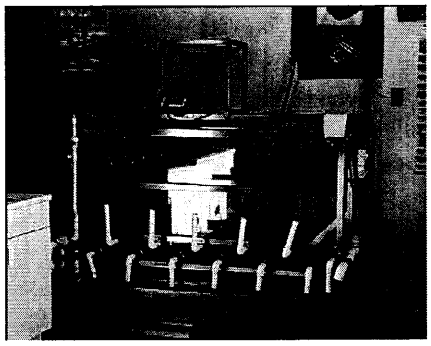


Figure 9. Flume

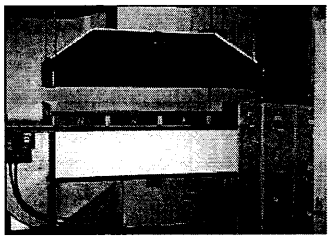


Figure 10. Seed dryer

Red Pine, White Spruce (Engelmann Spruce, Sx Spruce, Sitka Spruce, Blue Spruce)

PREVAC®—Pressure vacuum, letting vacuum pump reach a maximum vacuum pressure of 20 inches of mercury for approximate run up time of about eight seconds, inclusive of run-up pressure.

INCUBATION, DRYING, AND SEPARATION

The principle for I.D.S. is that only living tissue can retain moisture. Dead and dying seeds will float by creating the precise density differential through dryback. Initially, metabolic activity within the seeds first needs to be mobilized before the sequence proceeds to its end.

Incubation

Represents a modified stratification and requires that seed be at a high moisture content (28% to 35%) to begin the process in alleviating seed dormancy. The seedlot is first given 24-hour aerated cold water soak, spun dry (removing surface moisture only) followed by three weeks in a customized refrigerated misting cabinet with temperatures of 2 °C to 5 °C and 100% humidity. Seeds are contained in a 6- by 28-inch acrylic tube fitted with a combination of nylon screening and gortex end covers held in place with friction rings constructed from nylon tubing that is fitted to the inside of the tube. The gortex end covering allows for free air exchange and moisture uptake by the seeds. The nylon screening provides a separation between the inner chamber and gortex, thus preventing the seed mass from blocking the air exchange across the membrane (Downie 1999). At this stage it is essential to allow for additional water and proper air exchange by the seeds to ensure that initial metabolic activity is not impeded and the seeds do not suffer anoxia. Rolling the tubes daily repositions the seed mass and ensures a close inspection of the seeds. The optimum seed mass per tube is 3.500 kg., but if necessary, the maximum seed mass per tube could be as much as 5.600 kg. Required humidification within the cabinet is provided using a Slat/Fin Electric Warm Mist Germ Free Humidifier®.

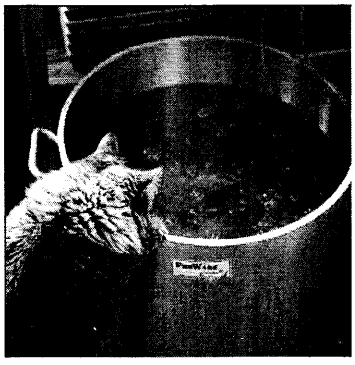


Figure 11. Soak pot c/w aeroators



Figure 12. Soak pot c/w aerators

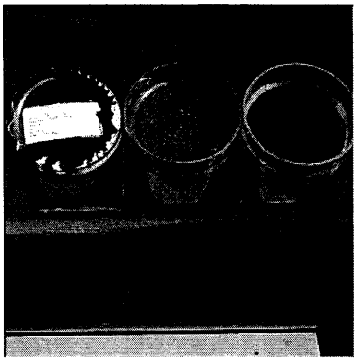


Figure 13. Tubes

Drying

Dryback is the procedure to effectively create a density differential and establish a sink/float ratio that matches the dead seed component from the most current germination test results. Marked sampling assessment over the drying period is used to establish when the separation point is attained. Prior to beginning the full drying phase, and this is the essential key to getting an optimum dryback period, the seeds are removed from their tube, placed into a nylon mesh bag, spray rinsed for part of the time while in the spin dryer and then put into the right side of our refrigeration unit at 2 °C to 5 °C where no humidity is added. We call this process Alternate Water Stablization (AWS). The seeds are uniformly spread within the bag on a screen shelf and left for a period of approximately 16 hours. This is a secret so don't tell anybody! Seedlots will lose some of their water over this time in varying degrees, from as little as 0.2% to almost 3% (2.73%), which is rather significant. When the seedlot exhibits a substantial moisture reduction it can indicate that dead/dying seeds are going to be removed from the seedlot quickly and that you just might expect an excellent germination increase. The example of 2.73% was from a black spruce seedlot that ended up with a germination capacity of 100%.

After completing the AWS step the seeds are weighed to determine their moisture content from the dry-weight calculation obtained after the pressure vacuum treatment or from initial moisture content information. The seedlot is now ready for the full drying phase. Depending how you feel about the drying times, intervals are very flexible: as little as 5 minutes to as much as 25 minutes, using a temperature range of 25 °C to 28 °C. The dryer used for our work is my own design and operates as a fluidized bed dryer giving the seeds the latitude to move within the tray. The dryer can deliver a maximum air volume of 1100 ft^3. A 4-speed fan gives effective control of air volume. Seldom has anything but the first selector position been used. An overhead hood and filtering mechanism provide dust removal over the drying phase. Seed drying can present a problem in this stage and rather than increase temperature it is much safer to increase the air volume.

At the finish of each drying interval, 2 x 100-seed samples are collected to assess the very important sink/float ratio. What you are trying to represent in this ratio is the dead fraction of the seedlot; in other words, if 91% was the initial germination, an average of nine seeds would be required as the floating fraction. To get to this average, successive drying intervals may be required, with varying time durations. You should need less time the closer you get to the marker point. As well as collecting the seedlot moisture content at each of these intervals, each 100-seed sample is weighed, to again note what has occurred and provide a tracking sequence.

Earlier, the separation flume had been filled with the appropriate water volume. To conduct the sink/float procedure, water is used from the flume only. This represents the exact water characteristics when the seed is ready for its separation stage. This is very important in order to ensure consistency between assessment and separation.

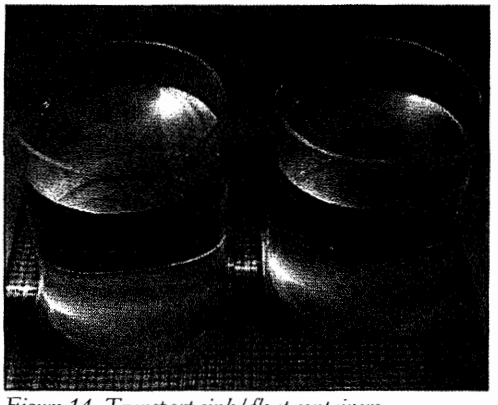


Figure 14. Transport sink/float containers.

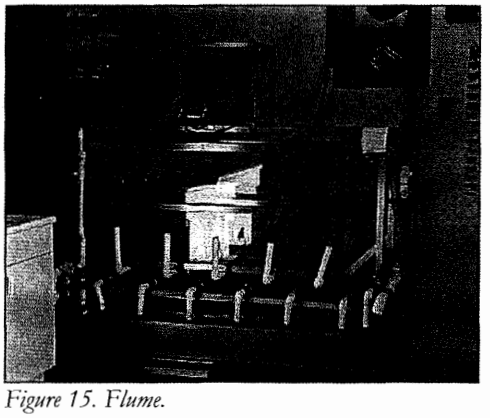


Figure 15. Flume.

The individual samples are dropped into separate transparent containers with water, stirred, and observed. Floaters are viewed by cut testing to look at anatomical structures present; in other words, empty seed, dead-filled and damaged tissues, and absent or immature embryos. As a general rule of thumb if the average floating seed number represents the dead fraction of the seedlot plus or minus one or two seeds, then it is ready for the separation stage.

When pressure vacuuming has been used in the treatment of jack pine (always) or lodgepole pine, new germination tests are set up using a 2-week stratification period (not a 3-week as in the incubation stage). This allows the upgraded PREVAC® germination results to be used in place of the initial germination information, establishing a float average using the most accurate germination value.

Separation

Separation occurs as dead and dying seed float while good seeds sink into sedimentation compartments along the bottom of the separation unit known as a separation flume. This particular flume has six bottom compartments into which the seed can settle.

Bottom fractions are termed as sinkers and identified as "B." These fractions sink and settle across the bottom of the Separation flume and are grouped as follows:

- B1 & B2—Highest and best fraction of living viable seed with the best germination/vigor. Appropriate for single seeding. Kept separate after separation.
- B3 to B6—Lower germination/vigor than found in the B1& B2 fractions. More appropriate for double seeding. Grouped as one after separation.

Top fraction seeds are termed as "floaters." This fraction floats and is regarded to be debris that contains the following:

- Weak, dead filled and empty seeds. There will be some germinates within this fraction, but germination capacity and vigor are low and a large number of abnormal germinates can be expected.

The seeds, now ready for separation, are poured into a nylon mesh bag. From the bag the seeds are introduced into the feed hopper of the flume. The seeds move along a vibratory channel at a slow, even feed rate into a water bath. By prewetting the seeds before being discharged into the separation tank, surface tension is released on the seedcoat. This limits air bubbles that might affix themselves to the seeds. Bubbles adhering to good seeds can cause undesirable events to occur such as a seed floating to the surface or extended travel in the water current, causing the seeds to end up in an alternate compartment with poorer quality seed. If bubbles adhering to seedcoats are a problem for you, devise a prewetting routine prior to separation.

Each seedlot will have its own sink characteristics with different fractional components. This means a seedlot could have a B1 and floaters only, while another could be made up of a B1, B2, B3-6, and floaters. This type of segmentation in certain cases is a judgment call and relies solely on the experience of the individual doing the treatment. Separated fractions can become too fine and can end up creating problems for a seeding system for which they were originally intended to provide enhancement. Don't get too fine, keep it operational!

Once the separation is completed, samples are removed from each fraction for moisture testing in order to calculate new dry weights and germination testing to validate that the separation work is completed. Seedlots have a moisture management routine, to ensure that the seeds are at a moisture level that will accommodate transportation even to far-ranging destinations and storage/handling prior to set seeding schedules.

Calculating Moisture Content

Moisture charting calculations eliminate a dependence on electronic moisture meters (weighing accuracy is a prerequisite).

1) Standard oven test with 1- or 2 5-g sample(s) to obtain moisture content (MC) of seeds.
2) Weigh seeds and record at this point; this becomes the fresh weight (FW).
3) After MC has been determined, calculate dry weight (DW) for the bulk lot.
4) Calculate the target fresh weight (TFW) and (if desired) calculate and construct a moisture chart for the desired target moisture content range (TMC).

a) MC = FW - DW/FW x 100 (oven test 17 hours at 103 °C)
= 5.000 - 4.254/5.000 x 100
= 0.746/5.000 x 100
= 0.1492 x 100
= 14.92%

b) DW = [1-(MC/100)] x FW
= [1-(0.1492/100)] x 240 g.
= [1-0.1492] x 240 g.
= 0.8508 x 240 g.
= 204.192 g.

DW100 = [1-(MC/100)] x FW100
= [1-(0.1492/100)] x 0.657 g.
= [1-0.1492] x 0.657 g.
= 0.8508 x 0.657 gm.
= 0.559 g.

c) TFW = DW/[1-(TMC/100)]
=204.192/[1-(14/100)]
= 204.192/[1-0.14]
= 204.192/0.86
= 237.432 gm.

TFW100 = DW100/[1-(TMC/100)]
= 0.559/[1-(14/100)]
= 0.559/[1-0.14]
= 0.559/0.86
= 0.650 gm.

Moisture Chart

A short cut to all of this goes like this; moisture test and calculate dry weight(s) as indicated. Determine your target moisture content desired and record the weight to which to dry the seed back. Seedlot (seed) moisture content can be obtained at any time by dividing the present weight of the seed being dried into the calculated dry weight and then subtracting that value from 100. The difference is the current moisture content for the seedlot (seed).

Moisture %	Weight in Grams	100 Seed Wt. in Grams
14.92	240	0.657
14	237.432	0.650
13	234.703	0.642
12	232.036	0.635
11	229.429	0.628
10	226.888	.0621
9	224.386	0.614
8	221.947	0.608
7	219.561	0.601
6	217.225	0.595

Prepared by Mishtu Banerjee; Scientificals Consulting/Kim Creasey; Nature's Common Elements

Results By Example: Successful & Not

It is a fact that most of the species and the corresponding seedlots treated through these upgrading procedures and protocols have very positive results and enable nurseries to utilize single sow applications. A small percentage of the seedlots treated for many and some undetermined reasons respond negatively to the processes.

The species that tends to return the most variable response is white spruce and more specifically originating from NW Ontario and parts of NE Ontario. It is very interesting to observe the varying characteristics and to try to hypothesize the question of "WHY." Many thoughts can come to mind depending on individual seedlot information and circumstances.

Questions to name a few;

- degree of dormancy versus modified stratification period—enough or too much
- correctness of initial germination information supplied
- pathogenic problems and corrective measures
- adequate moisture levels—too much or not enough
- inhibitory effects attributed to decreased water permeability (Baron 1978; Downie 1999)
- decreased oxygen permeability (Koslowski and Gentile 1959) (Downie 1999)
- restriction of expansion of the megagametophyte and embryo (Asakawa 1956; Downie 1999)

As difficult as it may be, the best one can do is "Read The Seed" to the best of your ability and to gain an intimate understanding of what is taking place biologically. Certain species tend to be very open to interpretation while others are very discrete and subtle.

Summary

This presentation was designed as a practical and operational approach with the intent of sharing some handy tricks and tips that you may find useful in your own program. Equipment used on our operation has evolved through a combination of imagination/necessity, the mother of all invention.

Reading the seed and understanding what is in front of you is your key to unlocking a multitude of secrets. "Follow and Observe Nature and You'll find the Common Elements." Treat the upgrading task as a challenge and have fun with it.

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FALL VERSUS SPRING TRANSPLANTING OF CONTAINER SEEDLINGS: A COMPARISON OF SEEDLING MORPHOLOGY

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Abstract

Containerized seedlings of Engelmann spruce (*Picea engelmannii*), sugar pine (*Pinus lambertiana*), Douglas-fir (*Pseudotsuga menziesii*), western redcedar (*Thuja plicata*), and western hemlock (*Tsuga heterphylla*) transplanted in the early fall and later in the early spring were compared for differences in stem diameter, height, root area, and shoot area. Fall-transplanted *P. mensizesii* and the *Thuja plicata* showed an increase in stem diamter of 13% (2.0 mm) and 4% (0.4 mm) respectively. Fall-transplanted seedlings developed larger root systems—*Picea engelmannii* by 18%, *Pinus lambertiana* by 48%, *Pseudotsuga menziesii* by 58%, and *Tsuga heterophylla* by 47%.

Key Words

Bareroot, plug+1, seedling quality, soil management

Over the past several decades, transplanted conifer seedlings (plug+1, 1+1, 2+1), have gained wide popularity among state, federal, and private land managers due to higher survival rates and better field performance (Tanaka and others 1988). This is largely attributed to the fact that transplants generally have greater root volumes, larger caliper, and lower shoot:root ratios than 2+0 seedlings. Developing cultural practices to produce a target transplant seedling at a competitive price is a constant challenge to the nursery manager. The results of a study that looked at one aspect of transplant culturing, the timing of transplanting, are reported in this paper.

Many nurseries transplant bareroot seedlings in the fall with very good results (Hahn 1990). At J. Herbert Stone Nursery in Central Point, Oregon, we have had poor results transplanting bareroot seedlings in the fall due to our warm, dry climate and the physiological status of seedlings in that season. For this reason we operationally transplant all of our seedlings in the spring between March and early June. Transplanting in the spring is not always favorable. Spring rainfall can keep us out of our fields for days, and wet soil conditions make it difficult to optimally prepare the soil, subsequently creating less than ideal root growth conditions. Furthermore, during the spring, our nursery is involved in many other work activities that include cultivating the fields that were lifted, culturing 2+0 seedlings and native grasses, and sowing 1+0 crops, all of which compete for equipment and personnel. Transplanting a portion of the stock in the fall would redistribute the workload more evenly throughout the year, creating more work in the fall, which is typically our slowest season. It would also allow us to prepare our soils when they are drier and more workable, less susceptible to compaction and puddling.

Our nursery decided to take another look at fall-transplanting because our eastern Oregon and eastern Washington clients were demanding a larger Douglas-fir (*Pseudotsuga mensizesii*) and Engelmann spruce (*Picea engelmannii*) transplant. These clients had recently switched from the 2+0 stock type to a plug+1 transplant because of the

difficulty of obtaining a large 2+0 seedling on a consistent basis. While our clients were pleased with 1+1 transplants, our nursery wanted to continue to increase overall seedling size by transplanting in the fall instead of the spring. We also wanted to evaluate the feasibility of transplanting western hemlock (*Tsuga heterophylla*), western redcedar (*Thuja plicata*), and sugar pine (*Pinus lambertiana*) in the fall to see if we could produce more balanced seedlings for these species.

Methods

The study was set up in a paired plot design with treatments replicated four times. All seed sources came from national forests in Oregon—western redcedar and western hemlock were from the Siulsaw, sugar pine from the Fremont, Engelmann spruce from the Umatilla, and Douglas-fir from the Wallowa-Whitman national forests. Seedlings were started in Styro 4A® containers that were sown at J. Herbert Stone Nursery in April 1998. They were grown under greenhouse conditions until late summer when they were moved outside to harden off. On September 30, 1998, seedlings for the fall-transplant treatment were extracted from the containers and immediately transplanted in fumigated fields. Seedlings were planted in 1.2 m (4 ft) beds in 7 rows at a density of 64 seedlings per square meter (6 seedlings/ft^2). No special culturing treatments were made on these seedlings from the time they were transplanted to the time spring-transplant treatment seedlings were planted. Seedlings for the spring-transplant treatment were maintained outside until they were extracted and processed on January 4, 1999. They were kept in freezer storage at –1 °C (30 °F) for three months, then thawed and transplanted on April 7, 1999, in beds adjacent to the fall-transplant treatment. From that point forward, seedlings of both treatments were grown under the same standard nursery growing regimes for Douglas-fir transplants. Seedlings were lifted on February 16, 2000.

Seedling morphology was measured on the fall-transplanted seedlings on September 30, 1998; on the spring-transplanted treatment on January 4, 1999, prior to freezing; on the fall-transplanted seedlings on March 2, 1999; and on both treatments on February 16, 2000. Stem diameter, top height, projected shoot area, and projected root area measurements were made on each seedling using Machine Vision Seedling Inspection Station® equipment. This is a high-resolution line-scan camera implemented on PC-compatible computer hardware, programmed to measure seedling morphological characteristics (Rigney and Kranzler 1994; Davis and Scholtes 1995). Machine Vision measures stem diameter at the cotyledon scar, shoot length from the cotyledon scar to the tip of the seedling bud and root and shoot areas as a two dimensional projection of roots and shoots, measured as cm^2. Root area has been shown to positively correlate with root volume in work reported by Davis and Scholtes (1995).

Results

There were significant differences in stem diameter for Douglas-fir and western redcedar between treatments. The seedlings from the fall-transplanted treatment had a stem diameter 13% (1.0 mm) and 4% (0.4 mm) greater than what had been measured in September, respectively (Table 1). Only the Engelmann spruce showed a significant difference in shoot length, with the spring-transplanted seedlings being larger by 15% (4.5 cm). Spring-transplanted Engelmann spruce seedlings also had greater shoot area while fall-transplanted seedlings of sugar pine and Douglas-fir displayed an increase in shoot area of 110% and 24%, respectively.

Transplanting seedlings in the fall produced larger root systems. All species, except western redcedar, showed a significant difference (90% confidence interval) between treatments for root area (Figure 1). Engelmann spruce increased by 18%, sugar pine by 48%, Douglas-fir by 58%, and western hemlock by 47%. There were no differences in survival for either the spring or fall transplants. Both treatments sustained less than 5 % mortality.

Discussion

The results of this trial support our decision to transplant containerized seedlings in the fall. One of our concerns had been whether the fall-transplanted seedlings could weather a cold winter. The winter of 1999 was a good year to test this because temperatures dropped to –15 °C (5 °F) for 4 days in January 1999. Seedlings did not frost heave or show any frost damage on the needles in the spring in response to this event. We attribute this to the fact that the root growth on fall-transplanted seedlings had extended beyond

Table 1.

	Picea emgelmannii	*Pinus lambertiana*	*Pseudotsuga menziesii*	*Thuja plicata*	*Tsuga heterophylla*
Caliper (mm)					
Fall-transplanted	9.8	5.9	8.8**	9.2**	8.3
Spring-transplanted	9.2	5.4	7.8	8.9	8.0
Shoot Length (cm)					
Fall-transplanted	25.9**	21.3	29.0	54.9	42.8
Spring-transplanted	30.4	18.7	28.2	55.9	44.6
Root Area (cm^2)					
Fall-transplanted	190**	92**	151**	150	259*
Spring-transplanted	162	62	96	120	177
Shoot Area (cm^2)					
Fall-transplanted	89**	78*	100*	423	271
Spring-transplanted	104	37	81	399	271

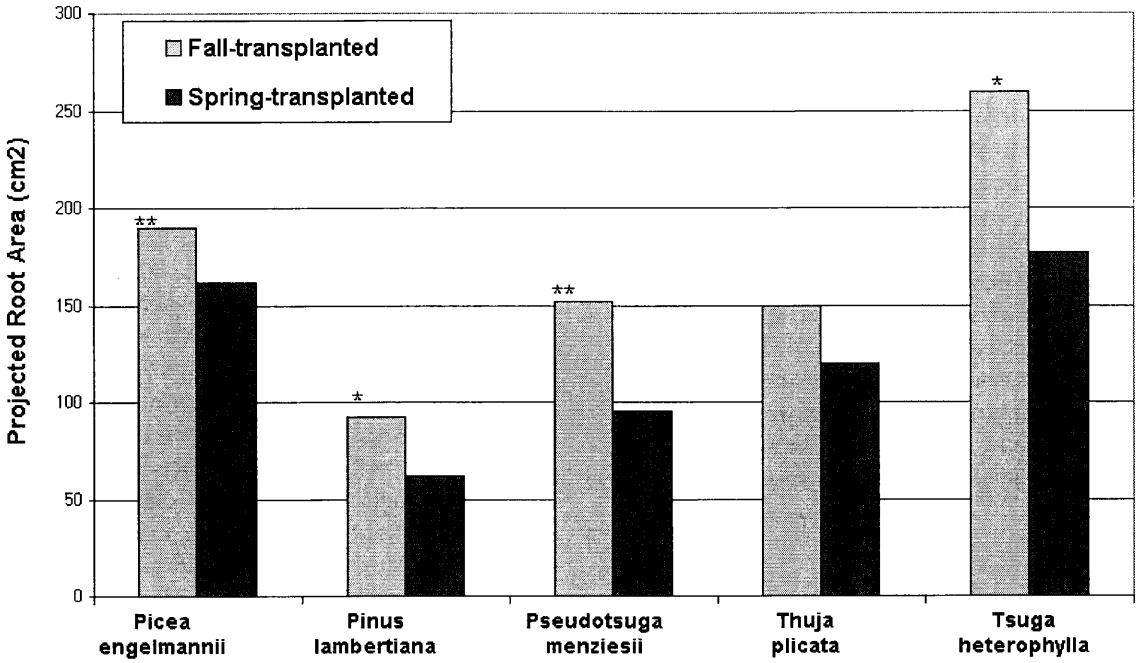
Within each morphological characteristic, the ** and * indicate significant differences at the 0.05 and 0.01 levels, respectively.

20 to 25 cm (8 to 10 in) in the soil by December, allowing seedlings to become anchored and have access to soil moisture below the frozen soil depth level of 13 cm (5 in).

The root growth period immediately after transplanting is very important for seedling establishment and growth. In the fall of 1998, after the fall-transplanted seedlings were planted, average air temperatures for October and November were 11 °C (51.5 °F) and 8 °C (45.7 °F) respectively. The warm temperatures, typical of our area, along with clear, mild days are favorable for root growth. Figure 2 is a conceptual drawing based on seedling measurements made at extraction of both treatments, in the late winter 1999 and at lift and pack, showing the difference between the growth of fall-transplanted and spring-transplanted seedlings after transplanting. We were surprised to see that the fall-transplanted seedlings did not develop more root area in the fall than the seedlings held in containers for the spring-transplanted treatments. Both treatments came into the spring with similar root areas. The difference was the fall-transplanted seedlings developed new roots that extended into the soil while the spring-transplanted seedlings continued to grow roots within the confines of the containers. As the seedlings of the fall-transplanted treatment began to grow in the spring, their root systems were already well established, which reduced the amount of "transplant shock" that is often observed in transplants. The seedlings of the spring-transplanted treatments, on the other hand, transplanted in April, missed the potential for root growth during the month of March. While the spring-transplanted seedlings were coming out of dormancy from cold storage, the fall-transplanted seedlings had already captured up to 6 weeks of root growth.

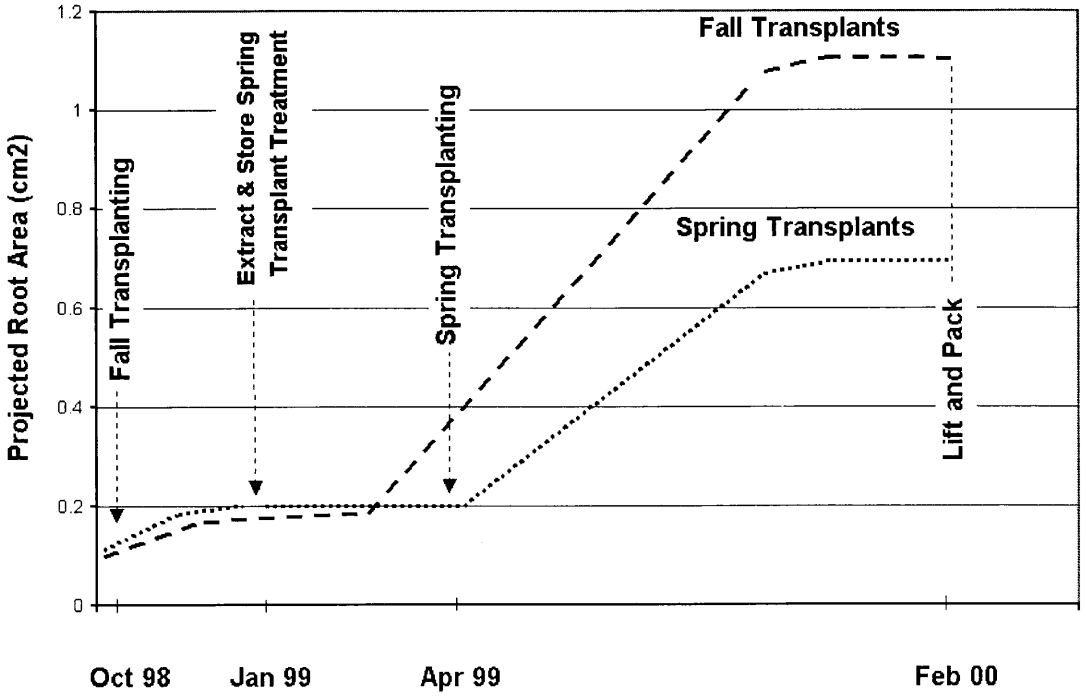
In addition to developing a seedling with better morphological characteristics, transplanting seedlings in the spring gives our nursery more flexibility in how we manage our work force, equipment, and soils. During the spring we hire two transplanting crews but often do not complete transplanting until early June. Moving a portion of this work to the fall can significantly reduce our spring workload while increasing workloads in the fall, which is typically our slowest time of year. It also will help in soil preparation because the soils in the fall are much drier and more workable than in the spring. On soils with moderate to poor drainage, soil preparation and transplanting in the spring, when the soils are wet, create soils that are compacted, puddle and lack internal drainage. Root growth and morphology can be severely affected by these soil conditions.

Figure 1



The ** and * represent significant difference from the spring treatments of 0.05 and 0.1 level, respectively.

Figure 2:



Our nursery expects to reduce the costs of our plug+1 seedlings by transplanting in the fall and eliminating the costs of extraction, storage, and handling that would be incurred if the seedlings were not transplanted until the following spring. Typically, spring-transplanted seedlings are extracted, placed in storage containers, frozen, brought out of storage and thawed, removed from their storage containers, and transplanted. With fall-transplanted seedlings, we simply extract seedlings in the greenhouses into tubs that go immediately to the transplanters. This eliminates storage containers, storage facilities, and the extra handling associated with this operation. From a seedling-quality standpoint, seedlings are handled once and held for only a short time between extraction and transplanting, which should reduce transplant shock.

Summary

The results of this study support our decision to transplant containerized seedlings in the fall. In early October 1999 we successfully transplanted 500,000 seedlings. Our plan for 2000 is to move the transplant date up to early September to capture the warm late-summer soil temperatures for greater root growth. Transplanting in the fall at our nursery will produce a more balanced, larger seedling at reduced costs, while allowing the nursery more flexibility in managing our work force and equipment.

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Approach and Rationale to Developing an IPM Program: Examples of Insect Management in British Columbia Reforestation Nurseries

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Key Words

Cutworms, aphids, lygus bug, root weevils, fungus gnats, container pest management

Insects, weeds, and diseases are a significant part of the production process that nursery growers must consider in order to effectively grow the desired conifer seedling. For the pests and seedlings, the underlying theme is survival, which encompasses 3 major components: stimulus, recognition, and response (Shigo 1991). Thus, the continuation of any system depends on its ability to recognize a stimulus that, in the case of the seedling, threatens or, in the case of the insect, enhances its survival. Once recognized, there must be the ability to respond rapidly and effectively. The speed and effectiveness of the response depends greatly on the availability of energy. In the seedling, reserve energy is used to mount a quick and effective block to any agent that threatens its existence. For the insect or disease, how fast the stimulus is recognized and the degree to which a response is developed are key elements to its survival. Every system has strong and weak periods; therefore, any pest management plan must target the most vulnerable phenological stage of the seedling or pest. Reforestation nurseries represent a unique challenge to the pest managers, as they are subject to pest problems originating from agriculture and forest pest complexes. In addition, conifer seedlings destined for reforestation sites are grown to strict specifications, therefore significantly reducing the nursery's level of tolerance to pest damage. Nursery managers are eager to reduce pesticide use to satisfy concerns expressed by nursery workers, tree planters, and regulatory agencies. The following is a summary of insect pest management strategies currently under development and implementation in British Columbia (BC) nurseries.

The majority of insect pests in conifer nurseries feed on the needles and shoots of seedlings. Many insects that are general feeders will readily attack young seedlings before their stems become woody and their needles become resinous. These insects are the most easily detected because pest presence or damage can be seen on inspection. (Shrimpton 1990; Sutherland and others 1989).

Cutworms

Cutworms, larvae of moths in the family *Noctuidae*, are chronic pests in conifer seedling nurseries. To date, 25 different species have been identified on BC nurseries. Though most are not true cutworms (family *Noctuidae*) they are, for all practical purpose, grouped under the term "cutworm." There are probably populations at all nurseries in every growing season, but the severity of the infestation varies greatly. All conifer species can be attacked, and the degree of damage is generally confined to young, succulent 1+0 seedlings. A single larva can destroy many seedlings in one evening, and only a few cutworms can destroy

thousands of seedlings in a couple of weeks. Cutworms feed on foliage and often cut through the stems leaving a short stump.

Pheromones are available for several species, but their use is jeopardized by the fact that nursery stock can be attacked by many different species, and cutworm populations can vary greatly from year to year. Due to the difficulty in predicting the occurrence of cutworms, controls must be applied after the cutworms or their damage have already been found. Traditional control methods have emphasised chemical sprays with permethrin or the biological control agent *Bacillus thuringiensis* (Bt). Unfortunately, Bt is limited in that it is strictly a gut poison. To be effective, the insect must consume enough treated plant material to stop feeding and eventually die of starvation. To counter this limitation, nurseries have implemented intensive scouting programs during the most susceptible period of their crop culture to quickly identify the first signs of cutworm damage. If found, nursery personnel are encouraged to hand remove and destroy small infestations of caterpillars. Otherwise, these areas are spot sprayed and monitored for damage.

In an effort to reduce the impact of these larvae, nursery managers employ a number of other strategies. Various weeds attract moths to oviposite, thus allowing larval populations to buildup in weedy areas in the nursery. These larvae then migrate to feed on the seedling crop. Weed management practices in and around the nursery site are a significant deterrent to pest establishment. However, once cutworms are present, killing the weeds may drive the larvae from the preferred weeds to the seedlings. At the beginning of the growing season, when the sides and roofs of greenhouses are in place, fitting screens over the intake vents and keeping the doors closed help to physically exclude these insect pests. Some nurseries have effectively reduced populations of adult moths in greenhouses by using light traps.

Aphids

Aphids are important pests in reforestation nurseries because of their feeding damage and the potential for transporting them to the field. Three species are of particular interest to BC nursery managers. They are the giant conifer aphid (*Cinara* sp.), the Cooley spruce gall aphid (*Adelges cooleyi*) and the green spruce aphid (*Elatobium abietinum*). The giant conifer aphid can be found on all species of conifers grown in reforestation nurseries and can cause stunting and chlorosis. The Cooley spruce gall aphid is a woolly aphid found alternating between spruce and Douglas-fir. It is easily detected because of its white woolly covering, but this also makes them harder to control. The green spruce aphid is primarily of concern on Sitka spruce seedlings. Like most aphids, these species have high reproductive rates, so populations can get out of control very quickly. Aphid infestations are often detected by the presence of wasps or ants, both of which will feed on the honeydew as well as redistribute aphids throughout the nursery crop. Because aphids can increase so rapidly under favorable conditions, chemical control may be necessary to protect plants. In the past, small infestations have been successfully treated with insecticidal soap while large infestations have been treated with diazinon. For the Cooley spruce gall aphid on Douglas-fir seedlings, nurseries are encouraged to remove mature spruce trees in and around the nursery site that serve as an alternate host for the gall forming stage.

A conifer root aphid, *Pachypappa tremulae*, has infested seedling stock at several nurseries in BC. To date, most infestations have occurred on container spruce, but related root aphid species also infest pine, larch, and Douglas-fir. These aphids are often discovered during the lift by their secretions of white waxy filaments, and they are often mistaken for ectomycorrhizae. Infestations are usually on the surface of the plug between the roots and the container wall, closer to the top of the plug than the bottom. The other stage in the life cycle is found on the leaves of trembling aspen (*Populus tremuloides*), where the aphids form structures known as leaf nests. Most nurseries that have sustained infestations of this aphid have not reported any damage. Outplanting studies have shown that they have no measurable effect on seedling performance, and as such no control strategies are recommended.

Two aphid predators, the convergent lady beetle or ladybugs (*Hippodamia convergens*) and the aphid midge (*Aphidoletes aphidimyza*) have been tested with promising success against the foliar aphids. Ladybugs are one of the best known of all insect natural predators. Both the larval and adult

ladybugs feed voraciously on a variety of aphid species. In fact, a single ladybug larva can consume 50 to 60 aphids per day. Ladybugs can provide long-term, adequate aphid control in a release area only if they reproduce. Test releases have found them to be successful in reducing aphid populations, particularly *Cinara* sp., but only when the aphid populations were considered high. A common problem is that adult female beetles cannot produce eggs until they have fed on prey, and they will only lay eggs where prey is sufficient to support the resulting larvae. Otherwise, they will disperse in search of more abundant prey. Strategies that have been developed to reduce the chances of dispersal are to make releases at dusk (ladybugs do not fly at night), immersing the adults in a sugar solution to reduce their flying abilities, and watering the release area to increase moisture levels. Also, distributing the total release of the adult ladybugs over a few days or weeks helps to increase the chances the adults will find favourable conditions to feed and lay eggs.

The female aphid midge is a gnat-like fly that searches for aphid colonies to deposit her eggs. The eggs hatch out as tiny orange maggots that can feed on 3 to 50 aphids per day. The larvae are known to attack at least 60 different species of aphids, and the adults are such efficient searchers that they can locate 1 aphid-infested plant among many aphid-free plants. Environmental conditions are important to the efficacy of the larvae. The adults prefer shady, humid conditions, and pupal stage survival requires moist soil or organic matter. The larvae stop development under short day length and overwinter as cocoons in the soil. This diapause can be prevented by the use of low-intensity supplemental lighting. Trial releases of the adult midges against the Cooley spruce gall aphid and the giant conifer aphid have shown them to establish in conifer crops and to reduce aphid populations. More effort is needed to develop an effective aphid monitoring program to facilitate the release of *A. aphidimyza* and *H. convergens*.

Lygus Bug

In North America, the Lygus bug (*Heteroptera:Miridea*) has been recognized as a severe pest of alfalfa, cotton, and garden vegetables. In the last 15 years, *Lygus* spp. have caused considerable damage to conifer crops in reforestation nurseries in North America and Europe. In BC, they feed on a variety of 1+0 container conifer species, but pines appear to be the most susceptible to damage (Sutherland and others 1989). Lygus bug damage has been found at almost every nursery in the province, although it is not always significant. Deformation of terminal shoots, loss of terminal leaders, flagging of the needles, and stem lesions are among the most common symptoms of Lygus feeding on seedlings. In general, damage is highest within the first few weeks after germination and declines sharply thereafter. Nurseries in BC use a preventive spray program of 2 to 4 applications of cypermethrin each growing season to prevent Lygus bug damage. Although the program appears to be effective, there are concerns over the development of resistance with repetitive applications of 1 insecticide.

To better define our integrated pest management (IPM) objectives, *Lygus* spp. surveys and trap screening studies were initiated to develop a better monitoring strategy to assist in the timing of the cypermethrin applications. Results of our 1997 survey of 5 coast and interior reforestation nurseries positively identified 5 Lygus species on lodgepole pine or western redcedar seedlings: *L. shulli*, *L. hesperus*, *L. elisus*, *L. lineolaris*, and *L. robustus*. The composition of Lygus species varied with each location. Results from the trap color, size, and location trials suggested that *L. shulli*, *L. hesperus* and *L. elisus* were stimulated to land on traps reflecting yellow and blue wavelengths (540 to 560 nm and 480 to 490 nm). These 3 Lygus species could, therefore, be monitored effectively with the use of yellow or blue sticky traps. Three sizes of plastic traps were used (small, 12.7 by 19.1 cm; medium, 17.8 by 19.1 cm; large, 19.1 by 30.5 cm) and positioned at 2 heights (5 cm and 30 cm) above the seedling canopy. In general, small traps caught more Lygus per trap and per cm^2 than the medium or large traps. More Lygus per trap and per cm^2 were caught on traps positioned 5 cm above the canopy than 30 cm. The differences in Lygus catches between trap sizes and heights were, however, not statistically significant, suggesting that any of these trap sizes or heights could be used for monitoring Lygus bugs in commercial nurseries.

Nurseries are now incorporating this preliminary monitoring plan to better time their insecticide applications. Some are also monitoring the

surrounding vegetation in an attempt to predict the arrival of Lygus bugs within the crop. If chosen, fringe monitoring should start when mean daily temperatures stay above 5 °C and continue until the flight peak of the first generation. More work needs to be done to better refine the monitoring program to link with seedling phenology and degree-day models.

Root Weevils

Several species of adult weevils have been confirmed or are suspected of girdling container stock, especially in greenhouses. Both the adults and larvae of root weevils can seriously damage seedlings, especially in coastal nurseries. The 2 most common species encountered in reforestation nurseries are the black vine weevil, *Otiorhynchus sulcatus*, and the strawberry root weevil, *O. ovatus*. The adult weevils usually affect young 1+0 seedlings by girdling the stem in a 1-cm wide band, usually on the fleshy part of the hypocotyl. Seedlings at the edges of the greenhouses and ones on the outsides of the styroblocks are attacked most frequently. Usually only 1 seedling is girdled at a time. Adult root weevils are elusive, feeding at night and hiding during the day. As a result, populations usually go undetected until damage occurs. The larvae are of greater concern because 1 larva can consume almost all the roots of a seedling and may girdle the stem just below the groundline. Larvae are extremely difficult to control with pesticides and because of this weevil control is aimed at killing the adults. Monitoring programs such as weevil boards, bait stations, pitfall traps, indicator plants, and sticky traps have all been tried without success. Cumulative degree-day (CDD) models have proved to be better at predicting the presence of adults. Based on the CDD models, permethrin applications are carefully timed to reduce girdling and to control the bulk of the adult population after emergence but before egg laying commences.

Entomopathogenic nematodes have shown promise in controlling weevil infestation. Numerous studies have shown them to be very effective against weevil larvae, especially in greenhouse container environments. They can be applied through conventional spray equipment with little or no modifications. To ensure greater efficacy, certain environmental and cultural conditions must be maintained in the seedling cavities. The nematodes must be applied to warm (above 10 °C), moist soils, and they must not be exposed to ultraviolet light. Due to the low cavity volumes in our container system, irrigation or fertilizer events must be minimized to maximize the nematode retention time in the seedling plugs. To date, test trials have shown them to be most effective against the later instars of the root weevils. In contrast, they are ineffective against the pupae or adults. In all, this has allowed nursery managers to target 2 root weevil life stages, thus enhancing their management strategy.

Fungus Gnats

Larvae of fungus gnats, most commonly *Bradysia* spp., can be a problem in container nurseries where populations build up rapidly under favorable conditions. Larvae infest containers with no apparent host preference, and they tend to feed on the upper roots. In heavier infestations, the larvae will strip the main roots and sometimes girdle entire stems. Adult fungus gnats are small (2.5 mm) dark colored, mosquito-like flies that are distinguished from shore flies by clear wings, long legs, and long, segmented antenna. Fungus gnats can complete their life cycles in about 3 weeks, so populations build up quickly under favorable conditions. Though the adults themselves do not feed, they pose a threat of transmitting soil-borne and foliar pathogens, and, in high numbers, are a nuisance to nursery workers. The best form of control is sanitation. The flies are attracted to areas of moss and algae on the styroblock containers to lay their eggs. Good drainage and removing all puddles of water from the greenhouse floors also helps. After the stock has been lifted the styroblocks should be washed and the greenhouses cleaned out and sanitized. Good cultural practices that produce vigorous healthy stock and proper irrigation to avoid overwatering will make the seedlings less attractive.

There are 2 biological control agents that are currently used for fungus gnat control. They are a soil-inhabiting mite, *Hypoaspis miles*, and entomopathogenic nematodes. The mite is a generalist predator that reproduces rapidly and moves well across soil, feeding on young stages of fungus gnats. This predator is well adapted to greenhouse environments and is most effective when used before fungus gnats become established or when the populations are low. Entomopathogenic nematodes are an alternative

biological control strategy if fungus gnat populations are high. These beneficial nematodes, *Steinernema* sp. and *Heterorhabditis* sp., do not attack the plants but actively seek out insect hosts. The juvenile nematodes, called infectives, enter the insect body and release bacteria that kill the host within 24 to 48 hours. After the nematodes have completed 1 or more generations, a new set of infectives emerges and begin the search for another insect host. The nematodes are effective at reducing high fungus gnat populations and can be used before the introduction of *H. miles*. The key to introducing these biological control agents for fungus gnat control is an effective monitoring program. Adult populations can be monitored using yellow sticky traps. Therefore, if fungus gnat adults are determined to be increasing, the modification of environmental conditions and supplemental applications of nematodes are effective in keeping fungus gnat populations in check.

Summary

As with all new initiatives in pest management, and in particular with biological control agents, care must be taken to understand all aspects of the control strategy to optimize its usefulness. The following should be integral components of any IPM program: 1) review traditional pesticide-use pattern; 2) choose an IPM strategy appropriate to the pest; 3) time the application of control strategies to coincide with the susceptible life stage of the target insect pest; 4) use appropriate rates; 5) monitor the efficacy of the strategy; and 6) experiment with monitoring methods to develop a knowledge base for your nursery site.

Pest management in conifer seedling nurseries is a relatively new field. As nurseries are becoming established in new areas and stock types change, new insects are becoming pests. As pests are discovered they are identified, their biology investigated, and management programs are developed using all available tools. Control methods are de-emphasizing the use of pesticides while monitoring techniques and cultural and physical controls are being enhanced.

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MYCORRHIZAL FUNGI AND TREES— A SUCCESSFUL REFORESTATION ALTERNATIVE FOR MINELAND RECLAMATION

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Abstract

Successful consistent revegetation of drastically disturbed mine sites (in other words, acid coal spoils and mineral waste dumps) throughout the United States and several foreign countries has been achieved by using the biological "tools"—tree seedlings, native shrubs and grass species inoculated with mycorrhizal fungi. These trees and shrubs are custom-grown in bareroot and container nurseries with selected mycorrhizal fungi and grasses and forbs are inoculated in the field with pelletized spores of VAM fungi at the time of planting. On disturbed sites, specific mycorrhizae formed by *Pisolithus tinctorius* (Pt), *Scleroderma* spp. (Sc) or species of VAM fungi provide significant benefits to the plants through increased water and nutrient absorption, decreased toxic materials absorption, and overall plant stress reduction.

One of the best examples of the practical application of this symbiotic mycorrhizal fungus-host tree technology on mined sites is in Ohio. During the past nineteen years, the Ohio Division of Mineland Reclamation—Abandoned Minelands Program (AML) has utilized the combination of selected ectomycorrhizal fungi (Pt) and tree species in a successful reforestation project to significantly improve the effectiveness and reduce the cost of AML reclamation projects. Since 1982, over 5 million PT-inoculated pine and oak seedlings have been planted on over 3,000 acres of unreclaimed AML sites. The sites are highly acidic (pH 2.9 to 3.4) and no soil amendments are used. Tree survival has averaged over 85% in the PT-inoculated tree plantings with less than 5% tree failures as compared with less than 50% survival and over 75% failures in previous plantings with the same noninoculated tree species. From 1982 to 1999, the Ohio AML reforestation project with Pt-inoculated trees has cost approximately $1.2 million or $388/acre. This represents an approximate 94% cost reduction as compared with conventional mineland reclamation methods ($6,000/acre)The Pt seedling inoculation cost is only $35.00/acre or about 9% of the reforestation cost which is relatively minute when compared to the consistent tree survival and early growth benefits obtained on these highly disturbed stressful sites.

Similar mineland reclamation success has been obtained on high-altitude, arid mineral mine sites in the western United States using selected mycorrhizal fungi inoculated trees, shrubs and grasses. Interest in the application of this natural, environmentally friendly, technology to mineland reclamation programs throughout the United States and several foreign countries is expanding. This "total natural systems approach" to successful mineland revegetation is available through a team of scientific and business experts offered by PHC Reclamation, Inc.

Key Words

Pisolithus tintorius, VAM, restoration, bareroot nurseries, container nurseries

Vast areas of the United States have been rendered nonproductive by over 175 years of intensive, uncontrolled surface and subsurface mining (Cordell and others 1991). Millions of acres of abandoned mined lands (AML) in the United States along with additional millions in several foreign countries (Asia, Europe, Africa, and South America) are in urgent need of reclamation. The 1990 Abandoned Mined Lands Inventory revealed that it would cost over $3 billion just to eliminate health and safety hazards on AML in the United States. An additional $57.8 billion would be required to reclaim environmental problem AML sites assigned third priority by the Surface Mining Control and Reclamation Act of 1977 (SMCRA). One northcentral state, Ohio, alone contains 200,000 acres of abandoned strip mines. Using conventional AML reclamation techniques (grading, recoiling, fertilizing, and revegetating), the cost of reclaiming these sites is estimated to be $3.5 billion. Problems associated with abandoned mineland include subsidence, acid or toxic drainage, landslides, sedimentation and flooding, loss of productivity, hazardous impoundments, visual pollution, and abandoned equipment (Cordell and others 1991). Mining for natural resources also generates a variety of waste materials that differ significantly in their biological, chemical, and physical characteristics. Factors such as soil ply, organic matter, composition, fertility, moisture, temperature, and microbial composition profoundly influence successful plant (trees, shrubs, and grasses) establishment and growth on these mineland sites (Pfleger and others 1994).

Increasing public awareness and intensified environmental legislation have regulated the mining industry to assure effective reclamation on mined lands. Since the enactment of SMCRA in 1997 (Public Law 95-87), active strip mine reclamation has focused on intensive soil grading, replacing topsoil, and establishing a dense herbaceous cover to quickly control erosion, thus assuring prompt band release. Although reforestation may not be the selected alternative in the reclamation of active mineland operations, it is receiving considerable interest as a viable reclamation "tool" in AML programs. Reforestation, of course, is neither new nor innovative. However, it deserves renewed interest and consideration for mineland reclamation applications. Tree planting on mined land is an excellent reclamation alternative that was de-emphasized during the time period in which alternative objectives, regulations and policies were developed following the enactment of environmental laws in the 1970s (Caldwell and others 1992). With today's technology, the land can be shaped to its former contour, the soil can be replaced to its approximate previous configuration, and acidic coal spoils and other mine wastes can be capped and sealed away from the environment. However, even with the most intensive procedures to improve soil fertility and structure, efforts to restore previously existing vegetation have all too often failed. Establishment of trees has been especially difficult, often requiring repeated plantings to offset recurrent mortality (Drake and Woodworth 1990; Marx and Amman 1979).

Mycorrhizae and Mined Sites

The feeder roots of most plant species (trees, shrubs, forbs, flowers, and grasses) are infected by specialized fungi that form beneficial associations called mycorrhizae (fungus roots). The most widespread symbiotic (mutually beneficial) association on plant roots is mycorrhizae. These structures greatly increase root absorption efficiency and are vital to the survival and growth of both the host tree and the fungus. Compared to non-mycorrhizal coats, those roots colonized by mycorrhizal fungi have increased water and nutrient absorptive capacity, nutrient fixation, resistance to root pathogens and longevity.

Mycorrhizae are of two primary biological types: endomycorrhizae (which penetrate host cells and predominantly occur on hardwood tree species, grasses, shrubs and forbs) and ectomycorrhizae (which grow between the root cells, cover the root surface with a mantle of fungus hyphae and are predominantly found on conifer tree species along with some hardwoods). Endomycorrhizae is the most widespread type with the major vesicular-arbuscular (VAM) group occurring on more plant species than all other types of mycorrhizae combined. Over 90 percent of the 300,000 species of vascular plants in the world form VAM in natural soils.

Ectomycorrhizae occur on about 10 percent of the world flora with numerous fungi forming ectomycorrhizae. In North America alone, at least

2,100 species of fungi form ectomycorrhizae with forest trees. The vast majority of plants in natural environments have mycorrhizae. It is the rule in nature. Therefore, a primary prerequisite of successful mineland reclamation with trees, shrubs, forbs, flowers and grasses is the most compatible combination involving the mycorrhizal fungi, plant host species and the soil and environmental conditions on the mine site.

One ectomycorrhizal fungus, *Pisolithus tinctorius* (Pt) has been widely used to improve tree planting success on mined lands. Acid coal spoils, kaolin spoils, mineral mine wastes, borrow pits, and other severely disturbed sites have been successfully forested with tree seedlings having Pt ectomycorrhizae. The fungus does not directly affect the quality of the mined site; it modifies the tree root system so that the tree can tolerate adverse soil conditions, such as low pH (3.0), high temperatures, low fertility, mineral toxicity, and drought, that usually kill other ectomycorrhizal fungi along with their host trees (Cordell and others 1991). Pt offers a practical, economical, effective alternative to intensive mineland reclamation, particularly on AML projects.

There is a large body of published scientific research showing the practical significance of the Pt ectomycorrhizae and specific VAM fungi to revegetation of mined lands and other adverse sites in the United States and other parts of the world. Most of these field research and demonstrations were done on very acid coal mined lands in the eastern U. S. that were also droughty with high summer soil temperatures and contained high amounts of Al, S, Mn, and Fe (Marx 1980). Other research and field demonstrations have been done on kaolin, phosphate and mineral mines, impoverished eroded soils and on borrow pit sites (Malajczak and others 1994). The results have all been similar. After several years, seedlings with Pt ectomycorrhizae or with selected VAM had significantly greater survival and growth and contained less heavy metals in their foliage than seedlings with natural origin ectomycorrhizae or VAM (Cordell and others 1995).

Nursery Inoculations and Seedling Production

During the past twenty years, operational programs have been developed for the practical and effective inoculation of bareroot and container nursery seedlings with Pt inocula for mineland reclamation programs. Pt was selected for its demonstrated benefits to a variety of host trees and for its adaptability to adverse soil conditions, ease of manipulation, and wide geographic and tree host range. Many conifer and some hardwood tree species on a variety of nursery sites have been artificially inoculated with Pt inocula. Effective Pt vegetative inoculum has consistently improved the quality of bareroot and

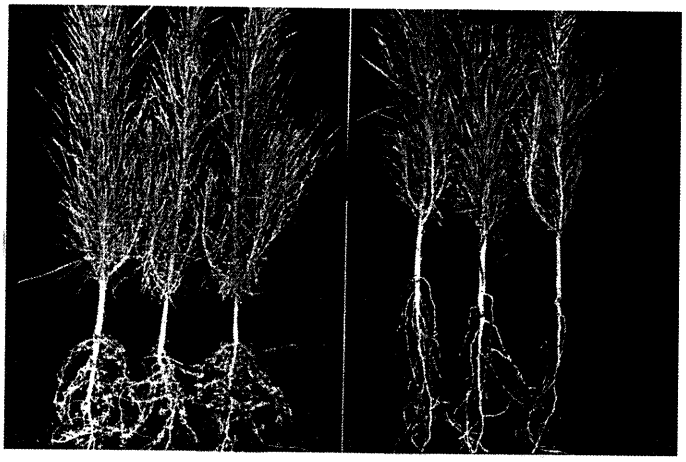


Figure 1. 1+0 loblolly pine seedlings with Pt ectomycorrhizae (left) and with only naturally occurring ectomycorrhizal fungi (right).

container nursery seedlings (Figure 1) (Marx and others 1981; Marx and others 1984) along with subsequent benefits to mined land reclamation and forestation.

Procedures for operational nursery use vary among the different commercial Pt inocula types. With any of the mycelium and spore inocula, the biological requirements of a second living organism are added to that of the seedling. Consequently, special precautions are necessary for the Pt inoculum during shipping, storage, and handling, along with certain aspects of seedling production, lifting, handling, and field planting. For successful Pt inoculation in bareroot seedbeds, populations of pathogenic and saprophytic fungi and native ectomycorrhizal fungi that may already be established in the soil must be reduced by spring soil fumigation. Prior to sowing, vegetative inoculum can be broadcast on the soil surface and incorporated into the fumigated seedbeds or it can be machine-applied with greater effectiveness and efficiency. For container-grown seedlings, vegetative or spore inoculum can be incorporated into the growing medium before filling the containers. Spores can also be sprayed or drenched onto container media for containerized seedlings and onto seedbeds in bareroot nurseries following seed germination and seedling emergence.

In the VAM program, bareroot and container nursery inoculations are expanding, using a multiple-fungal species VAM fungal "cocktail" inoculum on selected hardwood tree seedlings, native shrub species, native flowers and grasses for mineland and forestation applications. Results of VAM fungal inoculations on a variety of hardwood seedling species in several eastern United States bareroot nurseries, on selected native shrubs in a western U.S. container nursery and on native grasses and flowers on a copper mine site in the western U.S. have all been positive (Marx and others 1998). Research on the consistent positive effects of VAM on eastern hardwood tree species has also been published (Kormanik and others 1982). A variety of ectomycorrhizal and VAM fungal species and inocula types targeted for specific applications such as mineland reclamation are presently commercially available from PHC Reclamation, Inc.

Guidelines for MycorTree™ seedling production are designed to maintain healthy root systems with abundant specific mycorrhizae. Development and retention of lateral and feeder roots, and mycorrhizae must be considered from seed sowing through seedling harvest and field planting. Nurserymen, field foresters, reclamation specialists, and tree planters must remain aware of the two biological components, the tree seedling and its complement of mycorrhizal fungi. Mycorrhizal fungi generally have similar moisture, fertility, and pH requirements as their host plants, but tolerance to extreme or adverse conditions varies among fungus species. Nursery soil and cultural factors that significantly affect mycorrhizal development include pH, drainage and moisture, fertility, fumigation, pesticides, cover crops, shading, seedling spacing and density, and root pruning. Soil fertility, soil and water pH values and water quality are three of the most limiting factors affecting the development of mycorrhizae in most bareroot and container nurseries. Soil fertility and irrigation should be based on the requirements of the seedling. Excessively high levels of phosphorus and nitrogen (particularly in VAM inoculations) along with excessive irrigation (particularly in containers and poorly drained seedbeds) should be avoided. Certain pesticides are particularly detrimental to specific ectomycorrhizae such as Pt, and they must not be used in conjunction with inoculations. Precautions are also warranted when using artificial shade on seedbeds or in greenhouses. Minimum threshold light quantities are required for adequate photosynthate production and subsequent mycorrhizal development. Proper seedling spacing and density along with custom-applied root pruning practices in bareroot nurseries contribute to high-quality seedlings with desirable height and basal diameter characteristics and maximum lateral roots and mycorrhizae development (Caldwell and others 1992). Seedling harvesting, handling, storage, and planting practices may also have significant effects on the retention of lateral roots and mycorrhizae. Mycorrhizae are delicate structures and special care must be taken during all stages of seedling handling to retain the feeder root system and the mycorrhizae. To maintain seedling quality, conventional nursery practices may require modification to minimize damage to feeder roots and mycorrhizae. Stripping of feeder roots has

severe negative impacts on seedling field performance (Marx and Hatchell 1986). During transfer of seedlings from the field to the packing room, and at all other times when seedlings are subject to direct environmental exposures such as wind and direct sunlight, special care is required to avoid drying of the feeder roots and mycorrhizae. The seedling packing procedure and packing materials may also have significant effects on the ability of the seedling to endure storage, maintain root system quality, and survive field planting. Cold storage is vital to slow seedling respiration and maintain quality particularly for extended storage periods. Numerous studies have documented the effects of storage time on seedling quality. For most tree species and their associated mycorrhizae, proper storage for 2 to 6 weeks at 36 °F is not detrimental (Cordell and others 1991).

Successful Mineland Reclamation

Seedlings with Pt ectomycorrhizae have been repeatedly used for successful reclamation of acid coal spoils, mineral mine wastes, kaolin wastes, borrow pits, and other disturbed sites throughout the U.S. and in several foreign countries. Positive field responses will follow successful Pt nursery inoculations, the use of suitable mineland reclamation techniques and procedures, and favorable mineland spoil and environmental factors. Extensive reclamation research has been conducted on custom grown seedlings with Pt ectomycorrhizae on disturbed and adverse sites of various types in the eastern U.S. In 1966, Shramm made the initial observations and report of the widespread association of Pt with pines growing naturally on harsh mineland coal spoils m Pennsylvania (Schramm 1986). Reviews by Marx (1980) and Cordell and others (1991) discussed improvements in survival and growth of seedlings with Pt ectomycorrhizae on these sites. Maximum benefits were obtained on the coal spoils having higher temperatures, lower pH, and greater moisture stress. In addition, foliar analyses of seedlings with Pt ectomycorrhizae from mined sites show increases in macronutrients and reduced levels of potentially toxic microelements. Marx and Amman (1979) found significantly more N and less S, Fe, Mn, and Al in seedlings with Pt than those with natural ectomycorrhizae on acid coal spoils in Kentucky. Consequently, these and other field planting results further substantiate the capability of Pt and other selected species of ecto- and endo-mycorrhizae fungi to mediate adverse factors on mineland sites. One of the best examples of the practical application of this mycorrhizal fungus tree technology is in Ohio where Virginia, eastern white, and loblolly x pitch pines and northern red oak *(Quercus rubra L.)* with Pt ectomycorrhizae have exhibited significant increases in tree survival and reforestation success when compared with standard nursery seedlings (Table 1) (Marx and others 1998).

Table 1. Tree survival and reforestation success following use of Pt pine and hardwood seedlings in 356 reforestation plantings on abandoned minelands in southern Ohio, 1982 to 1999.

Seedling Treatment	Average Survival %	Planting Success %
Pt-inoculated	85	95+
Non-inoculated	< 50	< 25

For the non-inoculated seedling treatment, standard nursery seedlings were used prior to the Pt program.

Since its inception in 1982, the Ohio Abandoned Minelands Reforestation Program has planted over 5 million Pt-inoculated pine and oak seedlings on over 3,000 acres of unreclaimed AML sites. The typical site is barren, eroded with a mixture of bench slopes and out slopes of 2:1 or steeper terrain. Over 95% of 350 plus sites have been hand planted by local contractors. The sites are also highly acidic (pH 2.9 to 3.4) and no soil amendments (in other words, lime, fertilizer or irrigation) are used. Tree survival has averaged over 85% in the Pt-inoculated tree plantings with less than 5% tree failures as compared with less than 50% survival and over 75% failures in previous plantings with the same non-inoculated tree species (Marx and others 1998). From 1982 to 1999, the Ohio AML reforestation project with Pt-inoculated trees has cost approximately $1.2 million or $388/acre. This represents an approximate 94% cost reduction as compared with conventional mineland reclamation methods ($6,000/acre). The Pt seedling inoculation cost is only $35.00/acre ($0.021/seedling) or about 9% of the reforestation cost. This is relatively minute when compared to the consistent tree survival and early growth benefits obtained on these highly disturbed stressful sites.

Similar mineland reclamation success has been obtained on a Utah copper mine that has been active for over 100 years and has disrupted more than 20,000 acres of land. The disturbed areas have extensive erosion, sedimentation of drainages, dust hazards and little or no satisfactory vegetation. The waste dump slopes are 1.SH:1.OV or steeper with highly acidic conditions. There are also numerous borrow areas with gravelly conditions and several large areas of mill tailings. There is little suitable topsoil readily available and subsoils range from poor to unsuitable quality. Also, this high-altitude mining site has low precipitation with freezing winter and hot summer temperatures. The primary reclamation objectives on the mine waste dumps were to mitigate the production of acidic water, stabilize the dumps, mitigate soil erosion and dust, establish vegetation and return the dumps to wildlife habitat use. Reclamation objectives for the borrow and mill tailings areas were to establish vegetation, eliminate dust hazards, mitigate soil erosion and return the land to beneficial use (Marx and others 1998).

A natural systems solution was the PHC Reclamation, Inc. approach to revegetation of this mining area. It involved the selection of site-suitable plant species and specific mycorrhizal fungi based on results from initial test plots. Biosolids were used as a soil amendment to improve the initial adverse physical, chemical and plant nutrients problems of some of the low quality soils (Marx and others 1995). Unique reclamation equipment for VAM fungal inoculation, seeding and erosion mitigation was also developed. VAM fungal spores in pelletized form and beneficial bacteria were developed for easy and controlled field inoculation. A container-Brawn tree and shrub seedling production program was established in a local tree nursery that included protocols for custom inoculation of trees and shrubs with specific ectomycorrhizal or VAM fungi and bacteria.

The results have been very positive. The client's objectives have been met and the compliance has been achieved with regulatory agencies. Survival and growth rates of several thousand preinoculated custom grown trees and shrub seedlings and the grasses, flowers and shrubs inoculated at seeding, have been significantly better than the non-inoculated plants. In addition, a reduction in reclamation costs ranging from 40 to 80 percent depending on the type of area being reclaimed has been provided to the client. These savings include both short-term project reclamation work and long-term maintenance.

Conclusions

Consistent research and field demonstration results obtained during the past two decades clearly and consistently demonstrate the benefits of utilizing selected ecto- and endo-mycorrhizal fungi for the custom production and/or field inoculation of MycorTree™ seedlings, native shrubs, forbs, flowers and grasses for application in mineland reclamation programs. Reforestation with selected MycorTree™ pine and hardwood seedlings is presently receiving widespread interest as a viable alternative in abandoned mineland (AML) reclamation programs in the eastern United States. Positive results have been obtained from the environmental extremes occurring in the moist East to the arid West of the U. S. Major scientific break-throughs in recent years have led to the commercial production of a variety of MycorTree™ products and their practical application in tree seedling nurseries, forestation and mineland reclamation sites. State-of-the-art technology also reveals the role of a "total integrated package" in successful mineland reclamation programs. The package includes consideration of site factors such as pH, toxicity, and compaction. Adoption of remediation practices such as subsoiling and soil amendments, the use of unique reclamation site seeding/inoculating equipment and selection of the most compatible plant species and mycorrhizal fungi for the planting site are combined in a holistic approach to effective practical mineland reclamation.

This "natural systems environmentally friendly approach" to successful mineland revegetation is presently available through a team of scientific and business experts offered by PHC Reclamation, Inc. Reclamation costs vary considerably depending on the products and services requested by the client and the location and complexity of the mine site.

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Forest Nursery Pest Management in Cuba

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Abstract

A systematic survey of methods to detect pests in forest nurseries before they damage plants was done. These surveys recorded the most important forest nursery pests during 18 years (from 1980 to 1998) and their geographical and temporal distribution in the principal enterprises in Cuba. Approximately a dozen insect species and three fungi species responsible for the major problems in forest nurseries in Cuba were studied.

The principal insect pests are: *Anomis illita* (Guer) (Lep. Noctuidae), a defoliator of *Hibiscus elatus* (blue mahoe); *Anurogrillus* spp. (Orthoptera, Gryllidae) a defoliator of *Tabebuia angustata* (white wood), *Samanea saman* (raintree), *Cordia gerascanthus* (cordia wood), *Cedrela odorata* (cigar box cedar); *Atta insularis* (Guer) (Hym. Formicidae) a defoliator of *Hibiscus elatus* (blue mahoe), *Pinus caribaea* (Caribbean pine), *Swietenia macrophylla* (Honduras mahogany), *Casuarina equisetifolia* (horsetail beefwood); *Draeculocephala cubana* (Hom. Cicadellidae) a defoliator of *Eucalyptus* sp. (Eucalyptus), *Hibiscus elatus* (blue mahoe), *Tectona grandis* (teakwood) and *Samanea saman* (raintree). The principal fungi are *Fusarium* sp. (damping off) for broadleaf spp., and *Lecanosticta acicola* (*Mycosphaerella dearnessii*) and *Sphaeropsis sapinea* (Diploid blight) in forest pine nurseries.

The integrated management of forest pests in nurseries in Cuba is discussed. Biological control is utilized but, with few exceptions, the current management of pests relies on chemical products. Finally, the status of pest management in forest nurseries and prospects for the future are discussed.

Key Words

Seedling, reforestation, disease, insects, fungi, cultural control, IPM

Insects and diseases and the importance of their control are a global problem in both agriculture and forestry. These pests are responsible for a 30% loss in annual crop production (Gramberg 1981). By comparison, it has been estimated that 11.7% of losses nationally are caused by pests in forest nurseries in Cuba (Forestry Direction 1992). The forest sector has a great environmental, social and economic importance in Cuba, where 21% of the surface is covered with forests (1,980,720 hectares of natural forests; 352,900 hectares of established plantations and 124,200 hectares of new plantations). To maintain this industry, there are currently 60 standard nurseries (from 100,000 to 1,000,000 seedlings) and 100 smaller nurseries (10,000 to 100,000 production), and the trend is for an increase in the latter. The Institute of Forest Research of Cuba (IIF) was created in 1969 as a FAO (Food and Agriculture Organization of the United Nations) project, and since then it has overseen the research in the forested areas in the country. The Institute has devoted much time towards the investigation of proper procedures for the healthy development of the plants in forest nurseries, having determined that this aspect is essential to obtain plantations with good quality. The country forest patrimony took over in 32 Integral Forest Enterprises (EFI) and 24 Establishments of the National Enterprise for the Protection of Flora and Fauna. Also, with the collaboration of the Vegetal Sanitary Research Institute (INISAV) (Department of the Agriculture), the programs for studying diseases and insects have been established and new technologies developed. During almost 30 years the IIF worked in the detection and the

determination of the most harmful forest pests, with the help of a structure that goes from the base (EFI) to the headquarters (IIF) (Hochmut 1984). As a result of this work, they identified more than 100 species of forest nursery pests, with additional information about their biology and potential for causing damage. Vázquez and others (1999) described the management of forest insect pests of Cuba. This paper discusses diseases and their effects in forest nurseries, as well as preliminary strategies and future perspectives for management of these nursery pests.

Methods

The methods, in essence, are the same as those presented by López and others (1999), involving a systematic sampling of various forest nursery types, including conifer, broadleaf, caesarian, eucalyptus, and mixed nurseries. The specialists from each unit take samples of the affected parts of the plants or of the harmful agent, register the information in terms of locality, soil type, age of the plant, and treatments applied. Finally, they make a preliminary diagnosis of the sample. The specialists from the Forest Experiment Stations (EEF) produce the Sanitary Control Cards, which include all the information on the affected plant as well as the source and preliminary diagnosis. They send the cards to the headquarters (IIF). If it is necessary to verify the diagnosis they also send samples of the harmful agents. In the laboratories of the IIF, the identity of the harmful agent is determined with the help of other institutions. Later, an analysis is carried out using all information, and treatments are recommended. It is possible that damage from mechanical or environmental causes can be confused with symptoms caused by insects or fungal diseases (Landis 1989). For this reason, it is important to inspect the seedbed systematically and to collect the samples as soon as possible. The final identification of harmful agents was a result of collaboration with specialists from the United States and Europe for both insects (Hochmut 1984) and microorganisms (Leontovic 1992).

General Pest Control Strategies

The intensive work in the control of forest pests in Cuba began in the 1980s. From the 1980s to the present, two general strategies of work were developed to achieve the most integrated pest management possible: 1) prevention, which is based mainly on cultural practices to achieve strong and healthy seedlings; and 2) control, which includes the identification of the harmful agents, the evaluation of the damages, and direct treatment. It was in the 1990s, during the development of organic agriculture and biological control, that a third strategy emerged—in other words, conservation. It should be clarified that these strategies are not mutually exclusive, but rather inter-related, and are not contradictory with those outlined by Cordel and others (1989).

Main cultural practices

- Seed collection: Collection varies according to the species, but most are gathered during the months of April to June.
- Timing of sowing: Sowing depends on the species, but generally starts from September and runs through March. However, blue mahoe (*Hibiscus elatus*) is sown from June to August.
- Soil mixes: Brown soil can be used with carbonate or arena-loamy soil, blended with 10% organic matter. In Cuba, for the traditional production of conifer seedlings, pinegrove soil is added, containing natural mycorrhizas, with triple superphosphate (chemical fertilizer) added. In the case of broadleaf spp., no chemical fertilizers are added; but natural fertilizers in the form of organic matter (compost, green manure, etc.) are used.
- Sowing depth: The seeds are generally sown to a depth of 6 to 8 mm.
- Irrigation: Irrigation occurs twice a day during the first 20 days, then once a day if one observes that the substrate is dry. Excess humidity should be avoided.
- Weeding: Weeding should occur whenever necessary.
- Length of growing season: The growing season generally lasts 3 to 4 months. However the meliaceous should remain in the nursery from 10 to 12 months.
- Lifting and packing: Plants should be transferred from the nursery to the field in boxes to avoid damage.
- Plantation establishment: Planting should occur at the beginning of the rainy season after rainfall has moderated.

Preventive practices

Preventive practices play an important role in controlling disease outbreaks. These practices include:

- Preliminary inventories of the nursery areas to identify potential disease problems.
- Plant less vulnerable forest species in problem areas and note the environmental conditions which may contribute to disease problems.
- Use seeds of good quality with certificate of agreement.
- Reproduce clones with tolerance or genetic resistance to diseases.
- Prohibit the transplanting of infected seedlings.
- The entire nursery is fenced to impede the entrance of animals or people that can introduce pests in immature stages (eggs, nymphs, etc.).
- Pesticides should be stored at least 200 m from housing and dining rooms, and be well protected from environmental factors.
- Seedling and seedbed surveys are carried out every 7 days (once per week) with the purpose of detecting damage or infection.

Problems observed with prevention

Occasionally, even with a system of intensive management, sanitary practices have not resulted in the elimination of weeds or infected seedlings. Seeds have also been planted without the Certificate by the National System for Certification of Seeds to guarantee their quality and purity. For such reasons, pests have continued to cause economic losses.

Results of the nursery pest survey

Several species of insect and disease pests have been detected in forest nurseries in Cuba, but among these, 9 species of insects and 3 species of diseases are found with greater frequency and have the capacity for greater damage to the seedlings. Information is also presented on the identification of these pests and their control.

The main insect pests are as follows:

1) *Anomis illita* (Lepidoptera: Noctuidae) Common name: Green worm of the blue mahoe.

It is a monophagous species that affects *Hibiscus elatus* (Majagua). The adults are grizzly brown colored moths, about 3 cm in size, that lay their eggs of clear green color on the underside of leaves or on the stem. The larvae that actually cause the damage are yellowish green in color and can reach up to 3 cm in length. During the larval stage, they live on the back of leaves and are usually hard to detect—in other words, it is difficult to distinguish them at first sight. The pupae stage occurs in the bottom of containers or in the seedbed at a depth of 2 to 3 cm. The pupae are reddish brown in color and measure up to 15 mm. The insect attack begins on the new leaves and will continue onto the old leaves. During the investigation period (1980 to 1998), this insect affected 500,000 seedlings of blue mahoe. Their presence was registered between May and August —in other words, practically during the entire nursery season. It is a nursery pest with national distribution. The largest incidence was during the years 1982 and 1984 in the EFI Cienaga de Zapata and Bayamo.

2) *Atta insularis* Guer. (Hymenoptera: Formicidae) Common name: bibijagua.

This is our largest ant and the most harmful. They vary in size, from 6 mm (working) to 18 mm (queens), and are of reddish dark brown color. It is a poliphagous pest of forest nurseries, but the most vulnerable species appear to be the Caribbean pine (*P. caribaea*) Pine of Mayarí (*P. cubensis*) and the Pine of the Master Saw (Sierra Maestra) (*P. maestrensis*). This pest is distributed throughout the country. The greatest damage has been observed in the nurseries of the Saw Crystal, Mayarí, and Nipe in the eastern zone. These ants are social insects that live in large nests built under ground. They transport and cultivate certain species of fungi on which they feed. The defoliation by these ants is observed generally in isolated seedlings, but from time to time they devastate large areas of the seedbed. The ants prefer well drained red soils. The damages are observed during the entire year, but the largest activity is immediately after the first rains of May and June, during the building period of the new nests. The symptoms of damage are easily seen because seedlings of any age can be defoliated, and both the old and new needles are cut to the base of the stem.

3) *Anurogrillus* sp. (Orthoptera: Grillidae)

They are seedling cutting crickets of typical form for the Orthopteros, with a thick body, and their jumping legs very developed. They are brown in color and measure approximately 3 cm in length. They are ground-dwelling insects and are hidden under stones, boards, or other objects during the day. During the night, they leave in search of food, cutting the seedlings in the nursery. They eat only portions of the seedling, especially the stem, and leave the remaining material abandoned. This is what characterizes its attack. They are present mainly during March and May, and mainly in the eastern zone of the country.

4) *Draeculocephala cubana* (Metc. & Brun.) (Homoptera: Cicadellidae)

Its body is triangular and green in color. The yellow-greenish head is planate and ends in the form of a spear. It measures approximately 6 to 9 mm. This insect is found in large numbers in Euclypts, blue mahoe, teak, *Samanea saman* and *Cordia gerascanthus* nurseries. Symptoms include seedlings which are twisted and chlorotic, ending in death. Prevention includes weeding and sanitation of the seedbeds and the surrounding areas. The insect has national distribution and is found during the entire nursery growing season, but is more harmful in the drought time, from April to November.

5) *Hypsipyla grandella* (Zeller) (Lepidoptera: Pyralidae)

The adult is a gray butterfly, from 25 to 38 mm in length. Its common name is the meliaceous shoot borer. It attacks the species of this family, mainly the cedar (*Cedrela odorata*).They also attack the mahogany of Cuban (*Swietenia mahagoni*) and the mahogany of Honduran (*Swietenia macrophylla*). It is distributed throughout the country, but is found mainly in the nurseries of the central region, especially in the Marsh of Zapata. It is more abundant in the months of April to July.

The principal diseases were as follows:

1) Damping off or fall of the seedling

This disease affects all species of pine and several broadleaf species. The disease is generally caused by *Fusarium* spp. that are endemic to the soil and normally do not cause damage, that is to say a saprophitic microorganism. However, under specific conditions of humidity and temperature, the fungus becomes a parasitic agent to the seedling. It is an especially aggressive fungi for the plants cultivated as bareroot. It is present during the entire year, but causes less damage from the end of November to the beginning of January. It causes the most damage during the 8 weeks following germination of the seedling. The symptoms of the damage are characterized by constriction at the root collar, which results in the wilting and the falling down of the seedling. It is an explosive disease that can result in the death of thousands of plants in 24 hours. This same agent can also cause root rot. But in this case, the plants become chlorotic and die without falling down. It is found throughout the country, but is most prevalent in the eastern region.

2) Brown Spot—*Lecanosticta acicola* (Thüm.) Syd

This disease is presently found only in the eastern zone of the Island—in other words, Baracoa, Guantánamo, Plateau of Mayarí and Master Saw. Its presence has not been confirmed in the central and western zones. Its host plants include Pine of the Master Saw (*Pinus maestrensis*), Caribbean pine (*P. caribaea*) and pine of Mayarí (*P. cubensis*). The fungi develop in the tissue of the needles, and development can occur throughout the growing season. Various symptoms are indicators of the disease. Symptoms include spots of different coloring on the needles with the most common symptom, called brown stains, appearing as small brown spots from 1 to 3 mm. In the center of these spots are the fruiting bodies appearing as rounded points of black. At the beginning of the infection, the needles maintain their green color among the brown spots. Later, when the spots grow and converge, the needles become reddish brown and eventually die back to the base. The needles desiccate and fall, producing defoliation and eventually death of the seedling. This disease is known as one of the most dangerous for the pines, since it can spread throughout extensive areas and destroy the majority of the seedlings in the nursery. Therefore, it is necessary to survey the area to locate possible sources of infection and avoid disease outbreaks.

3) Die back of conifer seedlings—*Diplodia pinea*

Plant hosts include *Pinus tropicalis* and *P. cubensis*. The distribution includes Havana and the eastern region. The pathology of this fungus is widely debated. Some authors consider this fungus to be a facultative parasite, without physiological effects in the plants, while others report it as a pathogen, capable of penetrating young tissue. Symptoms of

the damage include invasion of needles of nursery pines, reduction in the germination of the seeds, root rots, and damping off. It is most prevalent during the months of May through July. It is frequently associated with scolyids of *Ips* and *Hypothenemus* genera.

Damping-off and brown spot comprise approximately 50% of the total forest nursery pests recorded in Cuba. Although insects in general showed a greater diversity in species, they had less impact and caused less mortality in seedlings. This was mainly due to the fact that insects are easier to identify and chemical treatment is more effective. Brown spot was the most dangerous diseases in this survey, with the highest frequency in the eastern mountainous region where the resources are scarcer and treatment is more difficult due to the topographical characteristics of the localities. In general, the forest species most affected were *Pinus maestrensis* (34%), *Hibiscus elatus* (24%), and *Pinus caribaea* (19%).

Estimation of Damage

To determine the magnitude of damage, the intensity of the symptoms on the seedlings from the corresponding pest, as well as its dispersal throughout the seedbeds, were measured. The intensity of the attack was measured by the number of parts of the plant affected (leaves, bud, and so on) divided by the total biomass. An attack was considered light if the plants were less than 30% damaged. An attack was considered strong if greater than 30% of the plant was affected.

Dispersal of the attack

The number of plants attacked in the seedbed was counted and was divided among the total of plants of the species in question. An infection/ infestation was considered light if 10% or less of the plants were affected. An infestation was considered strong if the number of affected plants was over the 10%. Subsequently attacks were classified into categories for treatment application. If the intensity and the dispersal are light, then it is placed in the light classification for damage. If the intensity is light and the dispersal is strong, then is placed in moderate damage. And if the intensity and dispersal are strong, then we classify it as strong damage and therefore utilize the stronger treatment. If the attack is light, we can choose mechanical control. The above shows the importance of systematic surveys, since, generally, nursery pests can be controlled when their incidence is observed before they reach large magnitudes.

Methods of Controlling Pests

Control of insects

The use of biological pesticides is not yet common practice. The application of synthetic insecticides such as carbaryl, diazinon, dimethoate and malathion still predominate. Nevertheless, at the beginning of the decade of the 1990's, we introduced the possibility of biopesticide treatments. When the evaluation of the damage was light, the use of biological products was recommended. However, in the majority of the cases, chemical application was necessary to obtain an effective control. In the case of the ants of the genus *Atta,* BIBISAV-2 50 to 100 g a.i. /m^2 has recently been used. But the results were always more effective when 15g Myrex was used at the mouth of each nest. Additional effective chemical control occurred when Formifol and Saubex (15 g a.i.) were used by mouth of each nest. Good control of cricket cutting of seedlings was obtained with the use of the pesticide Malathion 1000 CE 88.7 at 0.2% a.i./has. When these attacks were increased, the application of Dipterex PS 50 at 0.5 to 1.6 kg/has was effective. For the control of *Draeculocephala cubana* and other sucking insects, we applied Clorpirifos CE-48 at 0.72 to 0.96 kg. a.i./ha when the attacks were light and DimethoateCE-40 at 0.4 to 1.0 kg./ha when attacks were strong. For the control of *H. grandella,* biological products such as the *Bacillus thuringiensis* (Bt 32 PH) at 4.0 L/ha have been used. When these products did not work, Dipterex was applied in similar concentrations.

Control of diseases

For the control of the diseases we do not use biological treatments. To control damping-off, an analysis of the soil is carried out. If pathogenic fungi is found in the soil, the seedbed is disinfected before sowing (at least 10 days before sowing). It is, however, more convenient to seek soils free of pathogenic fungi. Chemical treatment against diseases should be applied immediately following appearance of the first symptoms. The use of Zineb 75% PH at 500 gr in 100 liters of

water is recommended, applying it at a rate of 7 liters per square meter. The applications should be done at intervals of 5 to 7 days, depending on the circumstances. Zineb 75% can also be applied in form of dust, depending on the target pest, on the affected seedlings.

Brown spot: Lecanosticta acicola

Seedlings should not be grown next to plantations that currently have or have had this disease. Chemical treatment should take place if areas display a 5% infection rate in the regions in which the disease has been observed (province of Granma, Santiago of Cuba, Guantánamo, and Holguín). Applications will occur using copper oxicloro 50% PH at 300 gr in 100 liters of water. In nurseries where the disease exists, the affected seedlings should be burned, with the seedlings within 50 m around the epicenter also destroyed. In these cases, treatment will be carried out every 7 to 10 days, maintaining the fungicide on the foliage for the longest possible time.

Diplodia blight: Diplodia pinea

The utilization of the systemic fungicide benomyl is recommended for control. The product should be applied as soon as symptoms of the disease appear. Elimination of the affected seedlings should also occur. If possible, resistant pines should be grown in these areas.

Future Perspectives

The new strategy of forest nursery pest management includes intensive and integrated management, keeping in mind the ecological focus of using biological pesticides and entomophagous insects. The production of mycorrhizal fungus in the laboratories of the IIF should also be considered in order to conserve the beneficial fauna and to protect the natural environment. In Cuba, the conditions for the implementation of such intensive integrated management programs exist in conifer and broadleaf nurseries. The network of 7 Forest Experimental Stations, with 2 sub-stations in Pinar del Río, help to carry out the expansion of technology and to contribute to the training of personnel in forest enterprises. There are 30 Territorial Stations of Plant Protection, as well as 48 centers of entomophagous and entomopathogen breeding in the Vegetal Sanitary National Center that offer biological products for the control of insect pests.

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FOREST NURSERY MANAGEMENT IN CHILE

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Key Words

Seedling, reforestation, plantation, propagation, radiata pine, Eucalyptus, micropropagation, bareroot nursery, container nursery

The forest economy in Chile is based on products from artificial reforestation efforts on approximately 2 million ha. From these, about 1.5 million ha (75%) are planted with *Pinus radiata*, 400,000 ha (20%) with species of *Eucalyptus*, principally *E. globulus* and *E. nitens*, and the rest (5%) composed by other species such as *Pseudotsuga menziesii*, *Pinus ponderosa*, *Pinus contorta*, and some hybrids of the genus *Populus*. Annual planting rates have varied from a maximum of 130,000 ha in 1992 to approximately 28,000 ha in 1999. This year (2000), the planting period is unfinished but is estimated to be similar to the previous year.

The rate of seedling production in the nurseries has varied from a high of 400 million seedlings to 100 million seedlings during the present year. The number of nurseries has oscillated from 850 to only 100 during the present year. This variation in number is explained by the change in responsibility in the establishment of the plantings and the ownership pattern.

Until the middle of the 1970s, the State Forest Service (CONAF) was the principal tree planter in the country. They established agreements with small and medium farmers, planting 54,000 ha in 1976. This corresponded to 50% of the total plantings in the country as a result of the 1975 Foment Law for planting.

Presently, many small and medium companies, both private and state, that participated in the establishment of the plantings have disappeared from the market. Now, around 1.5 million ha of forest belong to only two companies. Of these, one company has concentrated seedling production in only one site. They own a central nursery of about 140 ha, with a production of about 25 million seedlings, and with the best possible technical level available in the country. The other company produces about the same number of seedlings divided across four nurseries. The rest of the seedling production in the country is distributed among small companies with less than 3,000 ha planted per year, and some private nurseries that, in total, produce less than 15 million seedlings. The state owns 18 small nurseries that, in total, produce less than 5 million seedlings.

The present document analyzes the principal activities and cultural practices currently applied for seedling production in the country. This includes different seedling propagation and production methods without considering the technologic level.

PROPAGATION FROM SEED

About 60% of the *Pinus radiata* production is from seed. Approximately 70% of the seed comes from seed orchards, with the rest from plantings under management. In the case of the *Eucalyptus* species, 96% of the seedlings are produced from seed. About 40% of this seed comes from seed orchards and the rest from plantings. In the specific case of *Eucalyptus nitens*, about 20% of the seed is imported from Australia.

In general, the available seed has more than 97% purity, with more than 80% germination capacity. Due to the high annual seed production, only the summer and fall harvests of the same year are used. Seed storage for more than three years is an exception, and only includes species with marked periodicity in cone production.

Pinus radiata is produced principally in bareroot nurseries, but a small portion is also produced in containers. Species from the genus *Eucalyptus* are principally produced in containers; however, *Eucalyptus globulus* and *E. nitens* are produced in bareroot nurseries.

Bareroot seedling production starting from seed

In Chile, bareroot seedling nurseries are established on a variety of soils and climates within the most concentrated planting areas, ranging from 72° 00' 00" longitude - 32° 00'00" S latitude to 72° 00' 00" longitude - 42° 00' 00" S latitude. Most nurseries are established on *Dystric Xeropsaments*, *Umbric Dystrochrepts*, *Typic Rhodoxeralp*, *Typic Melanoxerands*, and *Ultic Palexeralfs* soils. The climate varies from maritime to Mediterranean, with annual precipitation from 350 mm to 2500 mm. The absolute minimum temperature at the canopy level varies from -1 to -12 °C, and the absolute maximum under the shade varies from 28 to 40 °C. The extreme temperatures are always registered in the central plains.

Pinus radiata

About 98% of the radiata pine seedling production from seed is in bareroot nurseries. Seed size varies from 17,000 to 46,000 seeds per kilogram depending on the family, seed orchard, and production area under management. After harvest and cleaning, seeds are classified by size. Even though the seed may come from the same family, the sized lots are treated as different lots for germination analysis, sowing depth and pretreatments. Sowing pretreatments are determined as a function of the viability, as well as germination capacity and germination energy relationship, varying from 24-hour soak in water at room temperature to 15-day stratification. A 24-hour water soak plus stratification is recommended for seed lots with differences greater than 15% between germination capacity and germination energy. A simple water soak is recommended for lower differences. All the nursery managers soak the seed in water for 24 hours to eliminate floaters. TMTD at a rate of 5 g/kg is applied to the seed to prevent damping-off.

Mechanized sowing is done at the end of the fall or early spring when surface (3 cm) soil temperature is less than 28 °C. Nursery beds are 1.2 m wide and include 8 rows 12.5 cm apart. The separation between seedlings varies from 4 to 8 cm depending on the soil productivity and the expected root collar diameter. Sowing depth varies from 5 to 15 cm depending on the size of the seed.

Most of the nurseries fertilize only with phosphorus during the establishment stage. There is a special interest to control damping-off, caused by *Pythium*, *Rhizoctonia*, *Fusarium* and *Phytophthora* fungi. These fungi are controlled by a combination of cultural practices and fungicide applications. Among the cultural practices are early sowings at low density and proper sowing depth, fungicide use in pre-emergence crops using specific products, or wide spectrum mixtures after emergence. Seedbeds are inoculated with native ectomycorrhizal fungi during the first crop of radiata pine.

Successive applications of oxifluorfen are applied as pre- and post-emergence weed control. Fluazifop-butil is applied in the specific case of grasses. Some nurseries use herbicides from the triazine group such as Simazine, Prometrine, and Atrazine. In general, nurseries are maintained free of weeds during the entire production process (9 months). Until now, none of the nurseries has used soil fumigants.

During the rapid growth stage, irrigation is applied when soil moisture decreases almost to the permanent wilting point. High levels of N, P, and K in the foliage are maintained before starting root management, which starts when seedlings have reached 80% to 90% of the target height. Root management consists of an undercutting at a depth of 12 to 15 cm, depending on the drought level of the planting site. In addition, wrenching is applied after one or two weeks depending of the environmental conditions at the nursery. Finally, a vertical root pruning is applied at the end of the root management period. During this stage, the principal sanitation problem in areas with high temperatures is *Macrophomina phaseolina*, a fungus

that can only be controlled through cultural practices such as irrigation and mulching. In addition, there are some problems with insects such as Thrips and *Rhyaccionia buoliana.*

During the hardening stage, the amount and frequency of irrigation are reduced in areas with more than three months without precipitation. In areas with summer precipitation, nitrogen fertilization is discontinued, phosphorus is maintained, and potassium is increased. Also, the frequency of wrenching is increased. Top pruning is applied to control height growth. During the second stage, at least 250 cold-hours (≤ 7 °C at the level of the foliage) are accumulated before harvesting. For seedlings destined for high moisture areas, the levels of Cu are increased through the application of cupric fungicides.

The most sophisticated nurseries evaluate the root growth potential by using special chambers, which regulate temperature, moisture, and oxygen to the root level. With this parameter, the correct harvesting time and seedling quality can be determined. The principal sanitation problems during this stage are *Botrytis* sp. and *Mycosphaerella pini* (*Dothistroma pini*) in areas with more than 2000 mm precipitation.

Seedlings are harvested early in the morning or late afternoon to avoid a decrease in the water potential of the seedlings. For this reason, some activities are done manually, except for one nursery that harvests seedlings mechanically. In the case of fall plantings, seedlings are planted as soon as possible, no more of 48 hours after lifting. During the winter plantings, after accumulating 700 to 1,300 cold-hours, seedlings are stored up to 30 days at 3 °C. Prior to shipping, roots are treated with a superabsorbent, using a local product (MVH-102) that maintains good root moisture conditions for a longer time period after harvesting. The seedlings are transported to the planting site in boxes, which are loaded in trucks with wind and sun protection. The most technologically advanced nursery transports and stores seedlings in refrigerated trucks.

Eucalyptus

About 5% of *Eucalyptus* species are produced in bareroot nurseries. However, during the establishment stage, these are grown in 5 to 7 cm^3 containers using finely ground composted radiata pine bark. Direct seeding of nursery beds is not practiced because of the high cost of the seed of some species, the low efficiency in its use, and the necessity of special protection—a scarce and expensive process in the country. In addition, some nurseries do not have an efficient weed program management before sowing, which is necessary due to the high-speed germination of *Eucalyptus.* For this reason, all bareroot seedlings are grown in a mixed production process where only the rapid growth and hardening stages are done under the bareroot system.

Sowing is mechanized, and in some cases, pre-germinated seeds selected by specific density are used. *Eucalyptus globulus* seed is soaked only in water while *Eucalyptus nitens* seed are pretreated with stratification. Generally, germination of both species is done in rooms or greenhouses with temperature control. Seedlings are transplanted when they have the first pair of true leaves. Transplanting is either manual or mechanical depending on the size of the nursery. When the operation is mechanical, they use 1.2 m wide beds with either 6 rows, 17 cm apart or 7 rows, 15 cm apart. Within the row, seedlings are 6 cm apart, with an average density of 96 to 112 seedlings/m. This process has reduced the production cost up to 60% for *Eucalyptus nitens* and 40% for *E. globulus.* In the case of species that require two growing seasons in the nursery (for example, *Nothofagus alpina*), there was a 75% reduction in the production cost.

During the last soil preparation prior to the transplanting, one-third of the total phosphorus is applied. The rest of the fertilizers are applied during the rapid growth stage in an attempt to apply optimal levels of N, P, and K. In both *Eucalyptus* species during the nursery stage, seedlings do not form mycorrhiza with ectomycorrhizal fungi, but only with endomycorrhizal fungi mainly of the genus *Glomus.* In the case of *Eucalyptus globulus*, the irrigation is applied when the available water has decreased 50%. However, for *Eucalyptus nitens,* water is applied after reaching the permanent wilting point. Oxifluorfen is used to control broadleaf weeds while fluazifop-butil is used for grasses. The applications of herbicides are repeated every 30 or 60 days depending on the weather conditions.

During the rapid growth stage, when the *Eucalyptus globulus* reaches approximately 15 cm in height, root pruning starts with undercutting the tap root. After this, wrenching is applied every 10 days followed by lateral root pruning at the end of the process. In *Eucalyptus nitens*, the tap root is undercut when the seedlings reach 80% of the target height. Wrenching is less frequent and the root management less intense than for *E. globulus*.

During the hardening stage, irrigation is gradually reduced for two to three weeks until the applications are determined by the permanent wilting point. At the end of this stage, top and lateral branch pruning is applied to *Eucalyptus globulus* to induce cold hardiness. In *Eucalyptus nitens*, only lateral branch pruning is applied. During the harvesting, roots are treated with superabsorbent polymer and protected against wind and sun during the transportation to the planting site. One of the advantages of this seedling production methodology for *Eucalyptus* is the reduction of sanitation problems during the entire production process compared to other production methodologies.

Seedling Production in Containers Starting from Seed

During the last five years, about 2% of *Pinus radiata* seedlings were produced in containers as a result of the decrease in the production rate of *Eucalyptus* species. Some nursery managers were forced to use containers to justify the investments. Seed management is similar to bareroot seedling production. The size of containers varies from 80 to 130 cm^3, either in blocks or individual plugs. Chemical root pruning is applied through the use of latex paint containing copper. Sowing is mechanized, putting only one seed per container with an efficiency greater than 95%. Composted pine bark is used as the growing medium, with particle size varying from 0.5 to 10 mm of diameter. Some nursery managers incorporate slow release fertilizer in the growing medium before filling the containers. Others prefer to apply soluble fertilizers through the irrigation system (fertigation) using different formulae and concentrations. Some others prepare their own mixtures. Most of the production is outdoors, using supports of 80 cm in height, and taking advantage of the environmental conditions at the end of the summer and early fall to harden the seedlings.

In the case of the *Eucalyptus* species, around 90% of the seedling production is in containers. Until the middle of the 1970s, polybags placed on the soil containing different soil mixtures were used to produce the seedlings. After this, there was a change to 60 x 40 cm polystyrene blocks containing 104 conical cavities, 7.5 cm deep, with a volume of 56 cm^3. During the 1980s the size of these changed to 84 cavities per block, 10 cm deep, with a volume of 80 cm^3.

Currently, many nurseries use 60 x 40 cm blocks with 84 cavities, 16 cm deep, with a volume of 130 cm^3 and a manufactured density of 28 kg/cm^2 for the styrofoam. Most of the nurseries use 100% composted radiata pine bark. Others mix the bark with 15% peat, and some others use 50% composted pine bark and 50% perlite.

Sowing is mechanized, putting 2 to 3 seeds per cavity. If more than one seed germinates, thinning is performed before the beginning of the rapid growth stage. During germination, most of the nurseries use polyethylene greenhouses with controlled temperature and the moisture near field capacity. After seedling emergence, irrigation is decreased until the root system reaches the bottom of the containers. Some nursery managers move the seedlings outdoors under shade-house conditions, especially when harvests are done during late winter or early spring. For those harvests between the fall and winter, seedlings are moved outdoors after emergence is complete. During the rapid growth stage, in general, there are two management regimes. The first maintains the seedlings under constant nutrient and water stress for nine months with a target seedling height of 20 cm without top pruning. The second is different from the previous one because, during the rapid growth stage, the moisture is maintained around 50% available water and this phase finishes with optimal nutritional levels. Top pruning is applied to the seedlings at a height twice the length of the containers. In this way, seedlings are more cold tolerant in the nursery and can be planted between fall and winter.

During the hardening phase, frequency and volume of irrigation is decreased trying to maintain seedling water potential levels below

0.7 MPa. In both species, the principal sanitation problem of this methodology is the attack of *Botrytis*. The use of mycorrhizal inoculation is needed as a cultural practice.

VEGETATIVE PROPAGATION

Pinus radiata

Since the 1980s, as a result of the genetic improvement program, *Pinus radiata* has been propagated from cuttings. Currently, about 40% of the seedlings are vegetatively propagated. One company produces about 30 million seedlings, of which 80% are propagated from cuttings. The rest of the nurseries are increasing the vegetative seedling production every year. The cuttings are obtained from mother plants originating from seeds of 1.5 generation orchards. Seedlings are produced as bareroot or containerized cuttings with two variants: seedlings from normal sized cuttings and microcuttings.

Bareroot Production

The hedges are initially established at a density of 32,000 to 40,000 per hectare. These are harvested for five years and then replaced. The rounded form produces the highest amount and the best quality of cuttings. However, due to the difficult management, many people prefer a flat top and an irregular form for the rest of the hedge, especially after three years and with enough cuttings. A good 3-year-old hedge plant produces around 40 high quality cuttings.

Collecting the cuttings is a key step in the process, since first, second or third order cuttings can be obtained. Among them, there is no difference in the rooting capacity, but the last two types can produce 5% to 8% more bifurcated seedlings than the first order. When there is abundant material, only first order and long cuttings are used. During the harvesting, the material should always be protected against wind and sun. The base cut should be as straight as possible without damaging the cambium. For this reason a scalpel is preferred for these cuts. If necessary, cuttings should be stored at 3 °C and relative humidity above 75%.

For bareroot seedling production, the ideal cutting should be 4 mm in diameter and 12 cm long. Most of the nursery managers use 10 cm long and 3 to 5 mm diameter cuttings. Cuttings with larger diameters produce larger seedlings. Harvesting of the cuttings begins during late fall and continues throughout the winter. These are inserted in the nursery soil up to half of their length, 7.5 cm apart within the row and 17 cm apart among the rows. This is about 90 cuttings per lineal meter of bed. Later, these are covered with plastic white shade cloth to avoid damage from wind and sun. After rooting, the shade cloth is removed, leaving the seedlings outdoors. From here, rapid growth stage is initiated and the general management is similar to those produced from seed. The only difference is that root management starts with a lateral root pruning followed by wrenching and a vertical pruning at the end. Similar to seedlings produced from seed, nutrient levels are maintained in optimal conditions.

The hardening phase starts with irrigation restrictions. Most of the nurseries apply top pruning at the end of the summer when the diameter growth is still possible. Harvesting is initiated after 600 cold hours in some nurseries. Before this chilling requirement is met, only seedlings from seed are shipped.

Currently, there is still controversy about the rooting form and grade of the cuttings. Some people think that more roots at the base of the cutting indicates higher seedling quality and greater stability after planting. During this winter, about 15,000 ha of 1- to 3-years-old plantings were severely affected by the wind. On the other hand, others consider that the origin and vigor of the roots is more important for quality of the root system. They consider that the wind problem depends more on the interaction of the soil characteristics, such as moisture, texture, depth, and structure, than the structure of the root system.

Production in Containers

Some nurseries produce vegetatively propagated seedlings in containers. They use 8 to 10 cm long cuttings with a minimum diameter of 3 mm, and containers with a depth of 16 cm and a volume of 130 to 140 cm^3. The substrate is a mixture of composted pine bark and 15% to 20% of peat.

The establishment phase in the nursery is done under a plastic cover with controlled temperature. Normally, rooting is faster under these conditions than outdoors. The rapid growth stage is the same under plastic cover or outdoors. The hardening phase is outdoors.

The goal is to produce seedlings with a height of 25 to 30 cm and diameter greater than 4 mm.

When abundant material from one specific family is needed, the microcutting propagation system is used. Seed from the specific family are germinated, and once they are 3 to 4 cm long, a 2 to 3 cm long cutting is removed. The microcuttings are placed in a substrate composed of 50% composted pine bark and 50% perlite, obtaining roots in a period of 25 to 45 days depending on the environmental conditions in the nursery. Whenever the seed propagated seedling produces new growth with the required characteristics, additional cuttings are harvested. In this way, in a period of 12 months, dozens of seedlings can be obtained from cuttings that normally are designated for hedge gardens. This process is done on hot beds with a constant rooting medium temperature from 20 to 25 °C. The environmental moisture should be above 70% and the mother plants should have good nutritional levels, especially nitrogen.

Eucalyptus

Less than 3% of the total production of *Eucalyptus globulus* is by cuttings. In the case of *Eucalyptus nitens,* the total production is less than 1%. Similar to radiata pine, the cuttings are obtained from hedges originating from seeds produced under controlled pollination. The cuttings are 7 to 10 cm long with diameters of 2 to 3 mm, with an optimum of 9 cm long and a diameter of 3 mm. In some cases, cuttings are treated with IBA in concentrations varying from 4% to 8%. The purpose is to stimulate the rooting, which is strongly dependent on the origin of the cuttings. There are some families with 100% rooting and others with 0% rooting. As an average, rooting in the modern nurseries is around 50%. It is estimated that, in the next 5 years, about 50% of the *Eucalyptus globulus* production will be cuttings.

Currently, cuttings are collected from middle spring to late summer with the optimal period during the summer. The containers (140 cm^3) are the same used for *Pinus radiata.* The substrate used as rooting and growing medium is composed of 50% composted pine bark and 50% perlite, which is amended with slow release fertilizer before filling the containers. The rooting process is done on hot beds, with a rooting environment temperature from 20 to 25 °C and the environmental moisture above 70%. After the establishment stage, when the new roots are longer than the length of the container, seedlings are moved to a sun protected area for approximately 30 days. Seedlings are then maintained outdoors until the beginning of the fall, when they are protected with shade cloth. Soluble fertilizer is applied after the initiation of the rooting process. At harvesting, 6 to 7 months after the rooting, seedlings have root collar diameters of 5 to 7 mm and height around 25 to 30 cm, with 5 to 6 leaf pairs. The principal sanitation problems are eventual *Botrytis* attacks, which are controlled with frequent applications of fungicides.

Application of Biotechnological Methods on Seedling Production

Similar to all forestry activities in Chile, the application of biotechnology to forest species is done only by the big companies. The most advanced micropropagation program using forest species is controlled by the Arauco Group, which has developed advanced micropropagation protocols for *Pinus radiata* and *Eucalyptus globulus.* This group, through its research institution (BIOFOREST S.A.), has initiated the acquisition of technology to increase their best clones through somatic embryogenesis. This is the most advanced group in this field. Other companies, such as Forestal Mininco S.A., have established micropropagation laboratories for *Pinus radiata* and *Eucalyptus globules,* but have had problems with the acclimation process and field establishment.

In addition, universities perform basic research to apply vegetative biotechnology to forest crops. The Universidad de Chile and the Pontificia Universidad Católica de Chile conduct micropropagation and somatic embryogenesis research in *Pinus radiata.* This research has received financial support from a group of forest companies that are smaller than the previously mentioned companies. The Universidad Austral de Chile has established a research center (CEFOR), which includes a micropropagation laboratory for *Eucalyptus globulus.* However, they are restricted in the propagation of forest species because they are using protocols from Japanese companies. The Universidad de Concepción has had a complete

forest biotechnology laboratory since 1998, where embryogenesis protocols for *Eucalyptus globulus*, *E. nitens,* and *Pinus radiata* have been developed. In addition, *in vitro* protocols for many native forest species have been completed. This laboratory has established acclimation protocols for *Pinus radiata* seedlings propagated *in vitro*, but *Eucalyptus* sp. protocols are still in process.

It is necessary to note that the massive seedling propagation *in vitro* is still developing in Chile. At present, only hedges are used to produce cuttings that will eventually be used to produce new seedlings. The principal reason for this is the high costs of this methodology compared to the traditional seedling production methods.

AROUND THE WORLD NURSERY INOCULATIONS AND CONIFER ESTABLISHMENT USING *RHIZOPOGON* MYCORRHIZAL FUNGI

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Amaranthus, M. 2002. Around The World Nursery Inoculations and Conifer Establishment Using Rhizopogon *Mycorrhizal Fungi. In: Dumroese, R.K.; Riley, L.E.; Landis, T.D., technical coordinators. National Proceedings: Forest and Conservation Associations—1999, 2000, and 2001. Proceedings RMRS-P-24. Ogden, UT: USDA Forest Service, Rocky Mountain Research Station: 226. Available at: http://www.fcnanet.org/proceedings/2000/amaranthus.pdf*

Rhizopogon is a large genus mycorrhizal fungi of particular importance to the Pinaceae. *Rhizopogon* species occur in both young and old forests, in diverse habitats and are present on every continent but Antarctica. This ecological amplitude was recognized early in the 20th century when *Rhizopogon* species were observed as dominant ectomycorrhizal fungi in exotic pine plantations. Establishing *Rhizopogon* in nursery inoculations at international nurseries has greatly benefited the establishment of North American conifer species around the world.

Rhizopogon are common, but often unnoticed, members of the mycorrhizal community where Pinaceae species are indigenous. *Rhizopogon* occurs naturally across the United States, in Mexico, Japan, China, Europe, and North Africa. Many new species in Europe and many other species in North America remain undescribed. Where conifers are not native (for example Australia, New Zealand, large areas of South America, and numerous islands), *Rhizopogon* species have followed their introduced conifer hosts into these exotic locations, often becoming dominant members of the introduced ectomycorrhizal flora.

Numerous factors make *Rhizopogon* a prime candidate for nursery inoculation program both nationally and internationally. Functional activities that benefit conifer outplanting performance include:

- *Rhizopogon* defends against diseases
- *Rhizopogon* is tolerant of a broad pH range
- *Rhizopogon* has high levels of enzyme and hormone activity benefiting nutrient acquisition
- *Rhizopogon* can utilize organic forms of nitrogen
- *Rhizopogon* protects seedlings against moisture stress
- *Rhizopogon* promotes successful conifer establishment and growth

Consequently, *Rhizopogon* has been the focus of considerable application research in forestry. The ease, viability and effectiveness of nursery spore inoculation is well documented. The low-cost nature of spore inoculation and the improved outplanting performance of *Rhizopogon* inoculated seedlings is driving increased use of *Rhizopogon* in forestry practice. Nearly 200 scientific papers have been published on *Rhizopogon* and this important body of information is now being put to practical use.

FOREST SEEDLING PRODUCTION IN ISRAEL

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Afforestation and reforestation in Israel are done on marginal lands, which consist of poor and shallow soils, with precipitation ranging from 650 mm in the north down to 200 mm in the south. Therefore, seedling quality is of great concern. All forest seedlings planted in Israel are produced by three forest nurseries which belong to the Forest Authority of Israel. About 3 million seedlings of about 30 species are produced each year (of which 54% are conifers).

During the last 10 years a major effort has been made to improve seedling quality. Seedling production involves the following aspects:

1. Seedbed—Seeds are germinated under controlled environment in germinating containers. Difficult to germinate species (like *Cercis siliquastrum*), receive special treatments before sowing. After germination the seedlings are transplanted to the growing containers.
2. Container volume—Conifers are grown in 240 cc Quickpot containers and broad leave species are grown in 330 to 600 cc. All seedlings are subjected to root-air-pruning.
3. Growing medium—consists of a combination of peat:perlite (7:3 v:v) with 2 g/liter of Osmocote. Incorporation of wetting agents is under study now.
4. Irrigation and Fertilization—The irrigation system is totally computerized and irrigation is done with sprinklers. Additional fertilization is applied through the irrigation system according to necessity.
5. Mycorrhiza—Mycorrhiza inoculation is still not a routine procedure in the nurseries but from studies done in the last 6 years a significant contribution of mycorrhiza to seedlings survival is evident.

The main studies at present focus on timing of planting, seedling hardening, the use of wetting agents and mycorrhiza.

PROPAGATION OF DRY TROPICAL FOREST TREES IN MEXICO

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There is a distinct lack of technical information on the propagation of native tree species from the dry tropical forest ecosystem in Mexico. This ecosystem has come under heavy human pressures to obtain several products such as specialty woods for fuel, posts for fences and construction, forage, edible fruits, stakes for horticulture crops, and medicinal products. The forest nurseries of the Government propagate only a limited number of native species to carry out forest plantations, and some of them are dangerous species. The objective of this paper is to present information to propagate 10 native trees useful to carry out the operation activities using traditional methods. The species are: Palo dulce (*Eysenhardtia polystachya*); guamuchil (*Pithecellobium dulce);* tehuistle (*Acacia bilimekii);* tepehuaje (*Lysiloma acapulcensis);* tepemezquite (*Lysiloma divaricata*); cubata (*Acacia cochliacantha*); cuahulote (*Guazuma ulmifolia*); brasil (*Haematoxylum brasiletto);* chapulixtle (*Dodonaea viscosa)* and cuachalalate *(Amphipterygium adstringens).*

Seed Collection Period. Palo dulce and cubata: November; tepemezquite and cuachalalate: December to January; tepehuaje and cuahulote: January to February; brasil and chapulixtle: February to March; guamuchil and tehuistle: April.

Initial Percentage of Emergence. Palo dulce (22% to 70%) and cuachalalate (30% to 60%) depending from the provenance of the seed; tehuistle: 36%; cubata: 39%; cuahulote: 60%; brasil: 64%; chapulixtle: 78%; tepehuaje: 84%; tepemezquite: 85%; and guamuchil: 90%.

Duration of Seed Viability under Storage In Natural Conditions. Guamuchil and brasil: one year; tehuistle and tepehuaje: 2 years; tepemezquite and palo dulce: 3 to 4 years; cubata, chapulixtle and cuachalalate: more than 5 years; and cuahulote: more than 8 years.

Seed Treatments. Palo dulce, guamuchil, tehuistle, tepehuaje, tepemezquite, brasil: soak in water under natural conditions for 24 hours; cuahulote: soak in water at 90 °C for 4 minutes, followed by a water soak under natural conditions for 24 hours; cubata: soak in boiling water until cool, then continue soak for 24 to 48 hours; chapulixtle: soak in water at 65 °C for 4 minutes, followed by water soak under natural conditions for 24 hours; cuachalalate: it is not necessary to extract the seeds from the samara fruits, wash the fruits with detergent and soak them in water under natural conditions for 24 hours.

Nursery Production Period. Tepehuaje and tepemezquite: 3 months; guamuchil, cubata and chapulixtle: 4 months; palo dulce, tehuistle, brasil and cuachalalate: 6 months; and cuahulote: 7 months.

PESTICIDES USED IN FOREST NURSERY MANAGEMENT IN THE UNITED STATES AND THE IMPACT OF THE FOOD QUALITY PROTECTION ACT AND OTHER REGULATORY ACTIONS

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The Food Quality Protection Act (FQPA) of 1996 has placed new standards on the registration and regulation of pesticides intended to protect children. The most significant changes mandated by FQPA relate to the registration process and the establishment of a risk determination process termed the "Risk Cup." This approach to risk analysis has resulted in greater restrictions on the application of pesticides used in forestry and in the loss of uses critical to natural resources management. This paper will discuss the current status of pesticides available for use in forest nurseries in the United States. The paper will also cover the potential future for new and currently registered chemical alternatives to methyl bromide.

Determination of the Season-Acclimation of Photosynthetic Apparatus by Heat-Induced Changes in Chlorophyll Fluorescence

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Resistance to damage from freezing temperatures is one of the most adaptive properties of "evergreen" (shoot bark, felloderma, needles) woody and bush plant tissues. Species-specific processes accompanying transition of chloroplasts to a frost resistant state (reduction of photochemical activity, the change of chemical structure and structural organization of thylakoid membranes) determine criterion for estimation of its seasonal dynamics. Information on the degree of frost resistance of chloroplasts is necessary for successful introduction of plants, and also important in determining measures for protection from light frosts. To determine the frost resistance of chloroplasts, it is possible to use of the heat transient of the zero chlorophyll fluorescence level (T-F curve) in conditions of gradual (2.5 grad/min) heating of "evergreen" plant tissue samples from 25 °C up to 75 °C. Preferable length of the exciting light wave is 400 nm, and light intensity – $3.4 \cdot 10^{-2}$ μEin • $m^{-2} \cdot s^{-1}$. Transition of chloroplasts to a frost resistant state is accompanied by suppression of the low temperature peak (about 50 °C) and significant strengthening of the high-temperature (75 °C) maximum on the T-F curve. The ratio of fluorescence intensities in the indicated peaks serves as a reliability parameter for the description of seasonal dynamics of frost resistance of various kinds "evergreen" plant tissue.

EFFECT OF DIFFERENT FORMS OF FUNGAL BIOPREPARATION FOR INCREASING QUALITY OF *PICEA OBOVATA* SEEDLINGS

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Gromovykh, T.K.; Malinovsky, A.L.; Koryanova, T.A. 2002. Effect of Different Forms of Fungal Biopreparation for Increasing Quality of Picea obovata *Seedlings. In: Dumroese, R.K.; Riley, L.E.; Landis, T.D., technical coordinators. National Proceedings: Forest and Conservation Nursery Associations—1999, 2000, and 2001. Proceedings RMRS-P-24. Ogden, UT: USDA Forest Service, Rocky Mountain Research Station: 231. Available at: http://www.fcnanet.org/proceedings/2000/gromovykh.pdf*

The current stage of societal development is characterized by ecological deterioration, with the application of chemicals for the prevention of pests and plant diseases giving rise to new problems in environmental protection.

Artificial forest regeneration in Siberia is due to annual wild fires and major human activity. Forest nurseries are located in these areas, which were previously used for growing agricultural plants. Due to this previous use, there is a problem of high seedling mortality from *Fusarium* spp. introduced to the soil with seeds and plant residues of cultivated crops.

Reforestation of Siberian forests is one of the most important tasks facing Russian forestry in the Siberian and Krasnoyarsk regions. The most dangerous pathogens of infectious damping-off for conifer seedlings are in the genus *Fusarium*, *Alternaria*, and *Pythium*, which are responsible for great losses of conifer seedlings in Siberia forest nurseries. The species with the greatest ecological importance in forest nurseries of Siberia are *Fusarium* spp. including *F.oxysporum*, *F.oxyporum* var. *orthoceras*, *F.moniliforme*, *F.sporotrichiella* var. *poae*, *F. nivale*.

Using integrated pest management, biological methods are becoming more available for the protection of conifer seedlings from diseases. *Trichoderma harzianum* is an effective biocontrol agent against several fungal soilborne plant pathogens. The objective of the present work was to examine two preparations of the beneficial *Trichoderma harzianum* (strain U): "Trichodermin C" and "Trichodermin BL." From 1995 to 1999, the biopreparations were tested in the protection of *Picea obovata* L. seedlings. Seedlings were grown in both a phytotron and in forest nurseries near Krasnoyarsk.

It was determined that application of the biocontrol agent had significant effect on height of *Picea obovata* seedlings. Use of "Trichodermin C" for seed treatment increased the growth of root systems, amount of needles and concentration of chlorophyll. It was found that a maximum quantity of healthy seedlings was obtained with the biological preparation "Trichodermin BL." From these results, it is evident that both preparations have commercial potential for use as biocontrol agents in the forest nursery industry as alternatives to chemical fumigation.

PROPAGATION OF TIDAL MARSH SPECIES NATIVE TO THE SAN FRANCISCO BAY

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Of the original tidal salt marshes around the San Francisco Bay, only about 5% remain. There have been many mitigation projects undertaken in this bay over the last 10 years. Depending on funding, projects have simply regraded the mudflats to provide habitat and some projects have included seeding or planting of native halophytic plants. However, most of these projects in which planting was done have included only the 8 or 10 most common species. The intact remnant marshes contain a diverse flora of 30 to 35 species. Monitoring of these projects has shown that the other uncommon but critical habitat species have not emigrated through natural processes into these areas. It is still salt marsh and provides valuable habitat but they could be a richer more diverse plant community.

At Crissy Field at the north tip of San Francisco, the Golden Gate National Recreation Area wanted to recreate a small portion of the original 200 acre salt marsh. Because only 20 acres were being recreated, a concerted effort was made to reintroduce every species for which a historic record could be found. Plantings in the winter of 1999-2000 included 15 species of native salt marsh plants that had not been previously grown in horticulture.

Germination pre-treatment experiments were performed for each species. These results will be reported along with seed collection and growing and planting tips for 20 salt marsh species grown for the first year at Crissy Field salt marsh.

Note: A complete paper can be found in the following publication:

Heimbinder, E. 2001. Revegetation of a San Francisco coastal salt marsh. Native Plants Journal 2(1): 54-59.

Also available at:
http://www.nativeplantnetwork.org

Native Plant Propagation and Habitat Restoration at Hakalau Forest National Wildlife Refuge, Hawaii

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Horiuchi, B.; Jeffrey, J. 2002. Native Plant Propagation and Habitat Restoration at Hakalau Forest NWR, Hawaii. In: Dumroese, R.K.; Riley, L.E.; Landis, T.D., technical coordinators. National Proceedings: Forest and Conservation Nursery Associations—1999, 2000, and 2001. Proceedings RMRS-P-24. Ogden, UT: USDA Forest Service, Rocky Mountain Research Station: 233. Available at: http://www.fcnanet.org/proceedings/2000/horiuchi.pdf

Hakalau Forest NWR was established in 1985 under the authority of the Endangered Species Act to preserve and protect five species of endangered forest birds and their rain forest habitat. While most of the 32,730 acre refuge is closed canopy forest, over one hundred years of cattle grazing, logging and burning have converted about 5,000 acres (2,023 ha) of upper elevation forest into open woodland and pasture dominated by introduced grasses. Other portions of the refuge encompass relatively intact native forest including some of the last montane, mesic koa-`hi`a (*Acacia koa-Metrosideros polymorpha*) forests in the world. These areas contain some of the highest densities of native forest birds in the State of Hawai`i as well as 29 rare and endangered plant species and the endangered Hawaiian Hoary Bat.

A primary goal for this refuge is to restore native forest in pasture areas enhancing and increasing native forest bird habitat and aiding in the recovery of endangered flora and fauna. The first crucial steps toward restoration have already been taken by eliminating domestic cattle grazing, fencing management units, and controlling weeds and feral ungulates, halting destruction of the forest, and allowing the process of natural recovery to begin. Natural forest regeneration in open pasture areas is very slow and is inhibited by lack of a native tree seed bank, exotic grass competition, lack of protective tree canopy, changes in soil conditions, and harsh micro-climates. Although Hawaii may seem like a tropical paradise, at Hakalau Forest NWR, propagation and out-planting programs have been fraught with many of the same problems found at other sites around the world, including frost, drought, insect pests, power and water limitations, weeds, and remote, high elevation constraints.

The refuge, with assistance from other federal and state agencies, has experimented with propagation and reforestation techniques. Since 1989, the refuge has had an extensive native tree planting program in which, with the help of many volunteers, over 175,000 koa trees have been planted within the upper elevation, most heavily disturbed, portions of the refuge. In 1996, a 30 X 96 foot greenhouse was constructed at the 6,400 ft elevation on the refuge and a horticulturist hired to manage and supervise the seed collection, propagation, and out-planting of native plants. To date, almost 40,000 native plants of 20 species, including 6 endangered species, have been propagated at the greenhouse and out-planted at the refuge. Prior to this, many of these species had never been propagated outside of the wild or out-planted for forest restoration programs.

PROPAGATING HARDWOOD SEEDLINGS IN LOUISIANA

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I. Introduction

A. Demand for hardwood tree seedlings is currently at an all time high.

1. The "no net loss of wet lands" law has caused increased activity in mitigating wet lands.
2. In Louisiana there is much activity with the Wetland Reserve Program with thousands of acres currently signed up for hardwood planting and waiting for hardwood seedlings.
3. The Conservation Reserve Program has also contributed considerably to the demand.
4. Louisiana is currently approximately 50% forested (13,900,000 acres), with approximately 63% being private, non-industrial forest (PNIF). Hunting is a way of life in Louisiana, and because of population increases, hunting is mainly on "hunting clubs." Hunting clubs improving wildlife habitat on both PNIF and industrial lands has also contributed to the demand.
5. There are also several other hardwood initiatives contributing to this increase in demand, such as Carbon Sequestration, Urban Forestry, and so on.

B. Hardwood seedling production in Louisiana has continually grown in Louisiana, not only in the state nursery production.

1. Approximately 9 new hardwood seedling nurseries have sprung-up in Louisiana, in response to the overwhelming demand for seedling production.
2. These new nurseries are for the most part "mom and pop" operations started by farmers who have idle land and farming equipment.
3. We do advise them on an "as requested" basis.
4. Most grow the easiest species and the most sought after timber species.

C. The State Of Louisiana, in our various names and departments, has been growing forest tree seedlings for almost 80 years.

II. Body

A. In the last 10 years, Louisiana Department of Agriculture and Forestry (LDAF) has seen its production increase from 1.2 MM hardwood seedlings to over 7 MM this year.

1. There has always been some interest in hardwood seedling planting in Louisiana.
2. Originally, only a handful of species were planted:
   a. Mostly reforestation species such as sweet gum, baldcypress, cherrybark oak, Nuttall oak, yellow poplar, cotton wood, sycamore, water oak, and so on. were planted.
3. Today, LDAF nurseries try to accommodate the needs of our clients and their changing needs.

a. New wetland programs need special nontraditional species for reclamation projects.
b. Wildlife habitat establishment and improvement require both traditional and nontraditional species.
c. Multiple use forestry, use of some traditional understory species.
d. We try to meet as many of the needs as we can.

B. Nursery practices to produce this many different species has proven to be quite a challenge.
1. The biggest challenge now is locating enough seed to plant the crops.
a. There are seed vendors who sell a large variety of seeds of traditional species.
b. There are professional seed collectors who will custom collect special needs.
c. We collect our own seed and process ourselves.
d. Demand for hardwood seed has also increased. This has caused a severe shortage in supplies because most hardwood seed planted in Louisiana is wild seed. Collection areas are becoming more scarce.
2. Wildlife biologist feel we collect too many seed and hurt wildlife mast supplies.
3. Desirable hardwood seed collection areas are mainly on public lands, and collection for profit regulations are becoming prohibitive.
4. Louisiana has begun to plant our own seed orchards, and convert progeny tests into seed production areas
5. Many different sizes of seeds, even within species, is a challenge to get sowing rates uniform.
a. Planting methods are from hand planting to machine planting.
b. We use commercial planters and equipment that we custom build ourselves, based on equipment we have seen for other functions but have modified for our needs.
6. Cultivation treatments for the different species, within the same fields, is also a great challenge.
7. Finding chemicals and correctly using them on the many different species has and will always be a challenge.
8. Inventorying all these species is also quite complicated.
9. We are currently still hand lifting and counting. Our soil and row spacing has not allowed us to get into automated lifting.
10. We generally handle an average of 900 orders on an inventory of 5 MM seedlings.

III. Summary
A. The demand for hardwood tree seedlings has seen a large increase in the past several years.
1. The increase is due to the fact that there are several new incentive programs that have increased interest in farming hardwood trees.
2. A new generation of landowners in Louisiana have also seen a need to reestablish hardwoods as a viable portion of their forest management systems.
a. To help improve the wildlife populations in their forests.
b. For aesthetics on their properties.
c. To establish "the natural state" of the original habitats.

B. As a response to the increased demand for hardwood seedlings, production has increased dramatically.
1. The state nurseries have increased production.
2. Many new private, and semi-private nurseries have started up in Louisiana.
3. This increase has triggered a shortage of seed availability and higher prices of seed.

NURSERY PRACTICES IN SWEDEN

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This paper presents containerized forest nursery practices in Sweden. Containerized stock was introduced some 30 years ago in Swedish forestry. Since then, the use of this stock has been successively increased at the expense of bare-root stock. Last year, approximately 400 million containerized and 30 million bare-root seedlings were produced in Sweden.

In the paper, the development of container design and the most common containerized systems used today will be presented. Container design has been focused on different principles for directing root growth during the production phase. The first systems introduced in the early 1970s implied stability problems for pine seedlings when planted in cold and dense soils. Since then a new generation of container systems have been developed with a design that prevents root deformations.

The paper will present common practices regarding growing densities, watering, fertilization and duration of growth, both in the greenhouse and the outdoor area. Also systems for blackout treatment for initiation of bud set in special outdoor areas and practices for cold storage during winter will be presented.

The presentation will also include information of some tests for operational seedling quality assessment done in Swedish nurseries today. These comprise a system to determine when to begin lifting in the autumn based on dry weight fraction of the shoot and detection of root damages or root vitality by measuring the root growth potential for a certain planting stock.

Finally, practices for seedling distribution to the planting area and the strategic distribution of plant boxes over the specific site are presented together with techniques for manual and mechanized planting.

THE FEDERAL FOREST STEWARDSHIP PROGRAM AND ITS IMPLICATIONS FOR SUSTAINABLE FORESTRY ON PRIVATE FOREST OWNERSHIPS IN THE UNITED STATES

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A 72 percent response rate was achieved in 1998 and 1999 national survey of 1,238 participants in the USDA Forest Service's Forest Stewardship Program, under which 130,000 individual multiple resource plans encompassing 16.5 million acres (6.5 million ha) of privately owned forest lands in the United States had been completed. Objectives were to determine if the plans were meeting the needs of private landowners and promoting long term sustainable management to meet public needs for wood products and other benefits. We found a very high rate of plan implementation and a high level of satisfaction with the quality of plans. FSP is reaching many owners who never before had received professional assistance in managing their forests; large numbers of participants are implementing new practices; are managing for multiple forest outputs; and frequently, are spending their own personal funds. Owners who received cost sharing for tree planting and other practices were almost three times more likely to implement their plans than participants who did not receive cost share assistance. Declining funding for federal cost share programs in recent (post survey) years raises questions as to whether FSP will continue to enjoy its current high level of success in promoting sustainable management on privately owned forest lands.

A Tour of Forest Nurseries in the Pacific Islands of Micronesia and American Samoa

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Forestry programs in the American-affiliated islands of Micronesia and American Samoa are relatively young, compared to those of mainland states. American Samoa and Guam have been American Flag Territories since 1899, but neither had a forestry program before 1970. American Samoa had no forestry program until 1987. After World War II, the United States was the *de facto* government in the Northern Marianas, Marshalls, and Eastern and Western Caroline Islands, many of which had been devastated by the battles. The United Nations made these islands "Trust Territories of the United States" under a formal trusteeship agreement that called for helping the islands to gain political and economic independence. By the early 1970s, things had normalized enough so that the Trust Territory Government was able to focus on natural resources management. It financed a crop of young Micronesian men to forestry school in Papua New Guinea, and the graduates returned in 1974 to 76 to take up positions with their home island governments. Forestry in those days was oriented strongly toward production of timber, and forest nurseries were aimed at production of timber species, especially *Swietenia macrophylla* (Honduras mahogany), which was seen as the value species of the future. In 1978 the USDA Forest Service, Pacific Southwest Region, stepped up delivery of State & Private Forestry programs to the islands beyond Hawaii. Nursery improvements have been high on the lists of the island foresters, and significant investments were made in expansions and improvements. Tom Landis accepted invitations to teach nursery management and to visit Pacific island nurseries for consultation and critique. Today the islands have nurseries that produce a great variety of plants, including ornamentals, and the emphasis is ever more strongly on propagation of native trees.

PROPAGATING NATIVE PLANTS AT THE NATIONAL TROPICAL BOTANICAL GARDEN

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Hawaii has the dubious distinction of being the extinction capital of the United States with close to 30 percent of native plant species listed as endangered. The National Tropical Botanical Garden has been a leader in efforts to propagate and conserve native Hawaiian plants with close to 800 species collected for *ex situ* conservation since 1990. Propagation methods have been determined for more than 500 species, including many which have never been cultivated before. Examples of the successes and challenges of propagating extraordinarily rare native Hawaiian plants will be presented.

USE OF A BENEFICIAL STRAIN OF *TRICHODERMA* TO PROTECT *PINUS SYLVESTRIS* SEEDLINGS

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Ryazanova T.V.; Gromovykh V.S.; Prudnicova S.V.; Tulpanova V.A. 2002. Use of a beneficial strain of Trichoderma *to protect* Pinus sylvestris *seedlings. In: Dumroese, R.K.; Riley, L.E.; Landis, T.D., technical coordinators. National Proceedings: Forest and Conservation Nursery Associations—1999, 2000, and 2001. Proceedings RMRS-P-24. Ogden, UT: USDA Forest Service, Rocky Mountain Research Station: 240. Available at: http://www.fcnanet.org/proceedings/2000/ryazanova.pdf*

In forest nursery practice, the mechanism of phytopathogen suppression by soil saprophytes is used to protect seedlings against root rot. An important stage is the formation and maintenance of a microbial association which will provide extended inhibition of phytopathogen development and growth of healthy seedlings.

To guarantee the effectiveness of seedling protection from pathogen infection and to maintain soil microbic coenosis stability in forest nurseries, the screening of active biocontrol strains is needed. Some of the prominent fungi for biological activity against fungal diseases belong to the genus *Trichoderma.* Strong antagonistic activity has been found in this genus toward phytopathogenic organisms. Therefore, one of the most important factors promoting successful introduction is to find the most active strains of fungi in this genus.

The purpose of our research was to search for strains that are active antagonists toward pathogens of pine seedlings, mainly damping-off caused by *Fusarium* spp. Five of the most promising isolates of *Trichoderma* were selected for inclusion a in disease suppression test. Isolates were screened for antagonistic activity towards the major damping-off pathogens of pine seedlings in the genus *Fusarium.* The best biocontrol candidate (strain MG) was selected. It was identificated as *Trichoderma* anamorph *Hypocrea gelatinosa.* Also, the best biocontrol candidate was examined for biotechnological indexes: dry weight of mycelia and yield of conidia. Next comparative studies were conducted on features of growth and sporulation on the various plant substrates obtained from post extraction residials of *Picea* and *Larix* bark and solid residuals of *Heliontus tuberosus L.*

Our work has demonstrated that beneficial *Trichoderma* strains can be used against phytopathogens in the genus *Fusarium.* From our experiment, we concluded that selected isolates are potentially biocontrol agents. The ability of *Trichoderma* strain MG to utilize plant substrates allows for creation of cheap biopreparations and will enable the use of this agent commercially. Preparation of the best biocontrol candidate for experimentation was prepared, and was called Trichodermin MG–97.

In our research during 1998-1999, the biopreparation MG–97 was tested for its effectiveness in the protection of *Pinus sylvestris* L. seedlings in forest nurseries nearby Krasnoyarsk (56° 04'N, 92°42'W). Results of our nursery experiments showed that biopreparation MG–97 may be effective in *Pinus sylvestris* seedling establishment.

FOREST NURSERIES IN VENEZUELA: CURRENT EFFORTS AND FUTURE PERSPECTIVES

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Current production of forest seedlings in Venezuela totals more than 100 million plants per year. There are four large nurseries that account for more than 75% of the total production with several hundred small nurseries that account for the remainder. Major species used are pines, eucalypts, mahogany, and numerous other native tree species. Limitations in forest nurseries in Venezuela include access to continued funding, improved seed availability and adequate nursery techniques to produce all of the desired species. Renewed interest in forest plantations in Venezuela has given rise to rapid expansion of nurseries in the last three years. The total number of seedlings could expand by 50% in the next 3 to 5 years.

NORTHEASTERN FOREST AND CONSERVATION NURSERY ASSOCIATION CONFERENCE

STATE COLLEGE, PA

JULY 23—26, 2001

USES OF THE WESTRUP BRUSH MACHINE

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Key Words

Seed processing, seed cleaning, seed conditioning, native species, National Tree Seed Laboratory, hardwood species



Figure 1. Westrup Brush Machine.

The Westrup brush machine can be used as the first step in the conditioning process of seeds. Even though there are various sizes of the machine, only the laboratory model (LA-H) is described. The machine is designed to separate seed from pods or flowers, dewing tree seed, remove appendages or hairs from seed, split twin seed, de-lint cotton seed, scarify hard coated seed, and polish seed.

Westrup manufactures the machine in Denmark. Unfortunately the shipping charges and money exchange rate increases its price. It weighs 90 kg. The motor, table, and vacuum cleaner can be purchased locally to reduce the cost. For use in the United States, it is equipped with 110 volt, 1 phase electrical connection, a US 3 prong wall plug, and operates at 1,300 watts. The entire brush machine is constructed of steel. The outer casing can easily be disassembled so the inside of the machine can be cleaned.

OPERATION

The seed is placed in the feed pan hopper positioned at the top of the machine. A larger (25 liter) feed hopper pan is available for large seed amounts. As the seed falls through the feeding funnel, the small metal paddles located at its mouth push seed into the shaft that houses the rotating blades. A vacuum cleaner hose attached to an opening above the mantle jacket removes fine dust. A powerful shop-vac works very well. Small seed and debris fall through the mantle into a collection pan.

The rotating brushes push the seed against the wire mantle creating a cutting action. Large seed and debris are expelled through the discharge gate into a collection pan at the front of the machine. A knob above the discharge gate turns to adjust the gate opening. The length of time the seeds remain in the shaft determines the amount of cleaning the seeds receive.

Brushes

Two nylon brushes are mounted on a main shaft, which rotates inside a wire mantle. The operator can adjust the revolutions by turning the speed knob located at the back of the machine. The brushes are adjustable in two directions, independent of each other and can be tilted in relation to the longitudinal direction of the shaft. Brushes vary in stiffness from soft, medium (0.50

mm) and stiff (0.90 mm). Medium brushes work best for most native plants that the National Tree Seed Laboratory personnel have tested. A metal setup gauge is used to space the brushes so they are the same measurement from front to back within the mantle. Brush width currently used at the National Tree Seed Laboratory is 23 mm. As the nylon brushes wear the width needs to be adjusted.

Mantles

The mantles are made out of square or round wire, perforated metal, or carborundum coated. The heavy square wire mesh has been used most frequently for conditioning native plants. Square wire is currently not made in the United States, so the mantles cannot be purchased separately from the machine. The mantle is not completely round, which aids in the movement of the seed inside. The mantles perch on two metal prongs on each side near the funnel, and the discharge gate has a set of the same prongs which slide into the front of the mantle holding it in place. When the jacket is removed, the mantle can be easily removed from the machine and cleaned. For most native plants, the best cutting action is achieved with the heavy square wire mantle and run at a high speed. Speed 11 out of a range of 1 to 12 is most frequently used. One exception was *Schizachyrium scoparium* (Michx.) Nash, which was conditioned at speed 8 and the seed was run through the machine twice. Sometimes the seed does not completely separate from its other parts during the first run, so more passes are necessary.

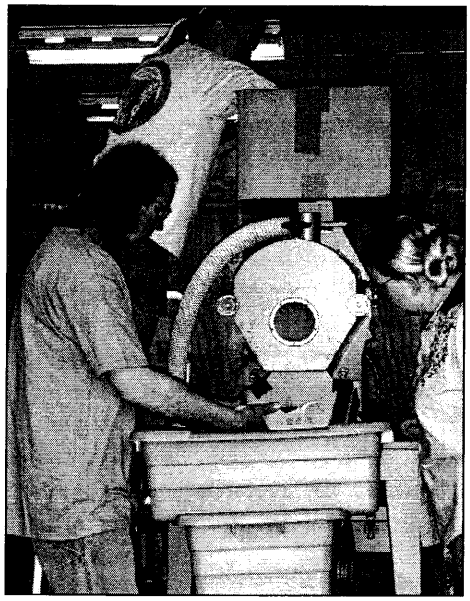


Figure 2. Operation of the Westrup brush machine.

Species

Many species of native plants can be conditioned with the machine. Conditioning orthodox seed (seed that can be dried below 10% moisture content) with wings, pods, awns, and husks works best. Orthodox seed of many wildflowers and native grasses have been successfully conditioned with the brush machine at the National Tree Seed Laboratory. The fleshy fruit of eastern redcedar *(Juniperus virginiana* L.) can be removed from seed, except the flesh gums up the machine and makes it hard to clean. Masceration is still recommended for fleshy fruited seed.

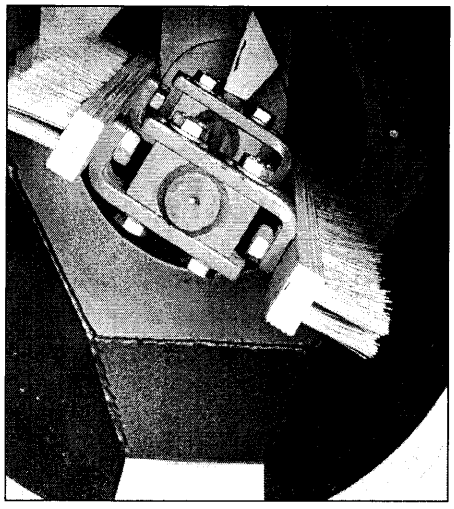


Figure 3. Brushes inside machine.

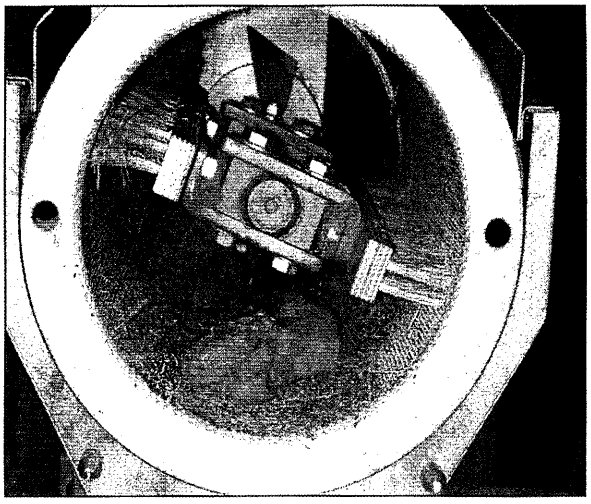


Figure 4. Brushes and mantle in use.

Conditioning protocols for several hardwood seed have been developed with this machine. Yellow-poplar cones (*Liriodendron tulipera,* L.) can be broken apart and the samaras dewinged with at least two passes through the machine (Karrfalt 1992). Fine strings are left from the cutting action of the wing in its first pass necessitating more runs. Once the wing is removed, the seed becomes more flowable and can be further conditioned with a specific gravity table.

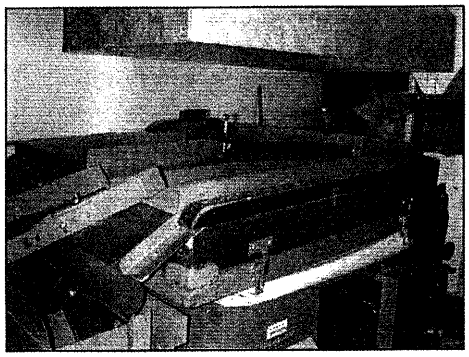


Figure 5. Specific gravity table for conditioning seeds.

Yellow-poplar is notorious for having a low seed set. A separation between full and empty seed can be accomplished on the gravity table because empty seeds weigh less than full seeds. For example, a 1,000 pound seedlot with 3% seed set will end up to be 30 pounds after the gravity table removes the empty seed. The higher viability seeds are easier to sow and manage in the nursery beds, which results in more uniform trees.

A difficult seed to clean, like the American sycamore fruiting heads (*Platanus occidentalis,* L.), can be easily conditioned with the brush machine. The fruiting heads are broken up by the brushes rubbing them against the wire mantle (Karrfalt 1992). Dropping too many fruiting heads down the funnel at once can stop up the machine and break the brushes and metal paddles. The fine dust is sucked out by the vacuum cleaner and the user does not come in contact with the dust, which may be harmful if inhaled. The individual achenes can be separated by weight with the specific gravity table.

Winterfat (*Eurotia lanata* (Pursh) Moq.) is a seed with hairs that can be successfully run through the brush machine (Karrfalt 1992). The fruit is a one-seeded utricle enclosed in 2 bracts each bearing fluffy white hairs. The pubescent, membranous pericarp is fused to the seedcoat. Again the rubbing action separates the hairs and bracts from the seed.

Winged seed, such as white ash (*Fraxinus americana* L.) and green ash (*Fraxinus pennsylvanica* Marsh.), can be singularized and dewinged with the brush machine to produce a flowable product that can be upgraded with other seed equipment (Karrfalt 1992). The key to successful dewinging is to dry the seeds enough so the wings break off instead of bending. This way, the wings are snapped and not shredded, which may damage the embryo.

The brush machine can substitute for a mascerator for dry legumes such as honeylocust (*Gleditsia triacanthos* L.) and redbud (*Cercis canadensis* L.). The pods are easily shredded allowing clean seed to emerge out of the discharge gate. Dust is removed by the vacuum cleaner. Long pod parts mixed with the seed can be extracted with a indent cylinder.

Seed Problems

Soft coated seed, such as red maple (*Acer rubrum* L.) and lacebark elm (*Ulmus parvifolia* Jacq.), can be easily damaged with the brush machine if run the same way as for hard coated seed. Sometimes the small seed falls through the holes in the mantle along with the fine particles and the larger seed emerges out the discharge gate with the larger chaff. Both bins have to be cleaned with aspirators, screens, etc. to extract the seed. For very small seed such as penstemon (*Penstemon canescens* (Britton) Britton), the brush machine is run without the vacuum so the seed is not sucked away. In this case the machine should be operated in a well ventilated room or outside for the protection of the operators.

Cleaning

The laboratory model of the brush machine is easily dismantled for cleaning between seedlots. There are no nooks or crannies for seeds to lodge, which makes cleaning fast and easy.

The discharge gate is first removed by unscrewing the two metal arms that secure it to the body of the machine. The vacuum hose can be disconnected from the top jacket before it is lifted off, exposing the mantles. Mantles are pulled straight out from the machine's body. Hand rubbing the wire mesh and vacuuming is all that is required for cleaning. Counter brushes come in

handy for removing stray seed and chaff around the machine.

People of both sexes and all heights can easily use the laboratory model. Extensive training and supervision are not necessary to learn how to operate the machine. However, a two person operation is recommended—one person to stand on the ladder and dump seed into the hopper, the other person to observe the seed expulsion so the bins do not overflow.

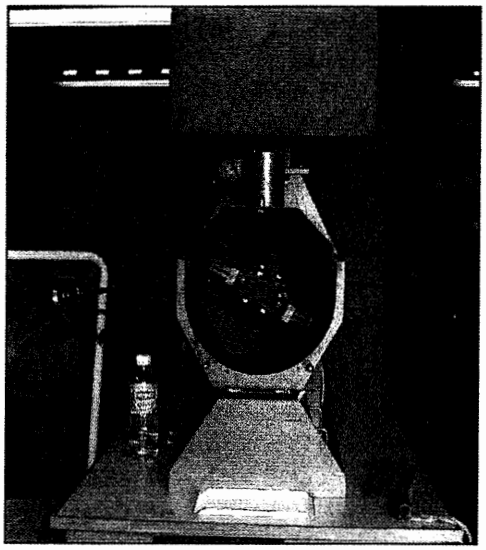


Figure 6. Cleaning brush machine between seedlots

Very small seed, such as *Campanula divaricata* Michr. and *Penstemon canascens* (Britton), are hard to see with the naked eye. Therefore, magnifying equipment is needed to distinguish seed from chaff. Magnifying lamps, dissecting scopes, and microscopes are most commonly used for viewing seed. Magnifiers allow the operator to view the condition of the seed and evaluate the conditioning operation. More passes through the brush machine or additional equipment may be needed to remove the chaff.

Additional Equipment

When seed and chaff are mixed together from the brush machine operation, additional seed conditioning equipment is needed. Aspirators are used frequently to separate trash from seed. Robert Karrfalt, director of the National Tree Seed Laboratory, built the aspirator pictured here for use with wildflowers and native grass seed. A fan is positioned on the top of the box to draw air instead of blowing it upward. The negative pressure created draws the small particles into the box and the seed falls to the floor in a pan. With this aspirator, a vibratory feeder delivers seed to the opening in the aspirator. Depending on the amount and size of trash mixed with seed, several attempts may be required to get the seed clean enough for sowing.

Large sticks can be removed with air screen equipment or hand screening. Seed and trash shape determine the type and size of the screen hole. Sticks and chaff that are longer than the seed are removed with an indent cylinder. Soil sieves come in handy for removing very small trash. Several sieve sizes and passes through the sieve may be needed to get the seedlot clean enough for sowing.

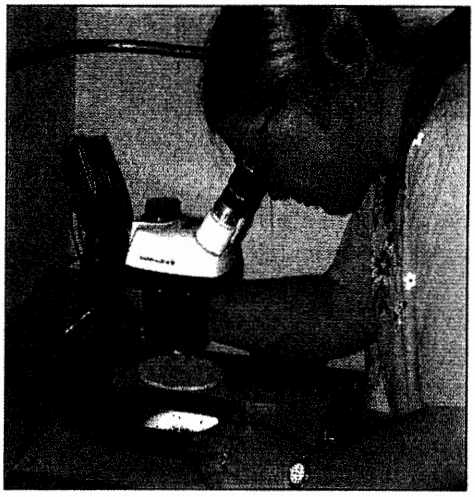


Figure 7. Microscope used for determining condition of the seed.

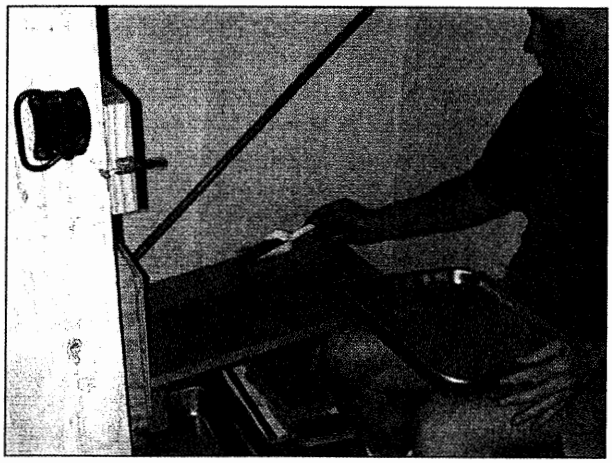


Figure 8. Aspirator for further seed cleaning.



Figure 9. Hand screening for removing trash from seed.

Conclusion

The Westrup brush machine is ideal for conditioning a wide range of orthodox hardwood, wildflower, and native grass seed. Many parts of the machine are adjustable, enabling the operator to customize the process for each species. The operator can adjust the flow rate of seed in the funnel, type of brushes used, speed of brush revolutions, brush width, mantle types, discharge gate opening, and so on. The laboratory model (LA-H) can condition small or large seedlots, which is very useful at a nursery that handles many different size seedlots. The steel construction is very durable, so it should operate a long time. Parts are easy to replace. Assembly or disassembly can be performed quickly and requires minimal cleaning between seedlots. Extensive training and supervision are not necessary, so various skilled workers can operate the machine. The price is prohibitive, which is a drawback.

The brush machine can be ordered in the United States from Westrup Inc., 1400 Preston Road Suite 400, Plano, TX 75093-5160, phone: (972) 985-7887, fax: (972) 985-7991, Email: westrupinc@aol.com Website: www.westrup.com

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WESTERN FOREST AND CONSERVATION NURSERY ASSOCIATION CONFERENCE

DURANGO, CO

JULY 30—AUGUST 3, 2001

RIPARIAN RESTORATION IN THE SOUTHWEST: SPECIES SELECTION, PROPAGATION, PLANTING METHODS, AND CASE STUDIES

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Dreesen, D., Harrington, J., Subirge, T., Stewart, P., Fenchel, G. 2002. Riparian Restoration in the Southwest: Species Selection, Propagation, Planting Methods, and Case Studies. In: Dumroese, R.K.; Riley, L.E.; Landis, T.D., technical coordinators. National Proceedings: Forest and Conservation Nursery Associations—1999, 2000, and 2001. Proceedings RMRS-P-24. Ogden, UT: USDA Forest Service, Rocky Mountain Research Station: 253-272. Available at: http://www.fcnanet.org/proceedings/2001/dreesen.pdf

Abstract

Riparian plant communities, though small in overall area, are among the most valuable natural areas in the Southwest. The causes of degradation of southwestern riparian zones range from excessive cattle and elk grazing in montane watersheds to invasive woody exotic species and lack of natural flooding in the cottonwood forests, "bosque," of low elevation river valleys. Goals of riparian restoration include erosion control, channel stabilization, runoff reduction, and enhancement of wildlife and fishery habitat. Plant species and stock types selected for restoration efforts must be appropriate for the site characteristics. Relevant site characteristics include elevation, soil texture and chemistry, and depth to water table. Vegetative propagation methodologies including pole cutting production, mound layering, and large containerized stock have been developed to provide cost effective plant production of riparian species. Plant materials and planting methods range from dormant pole cuttings placed vertically or horizontally to unusual container stock types such as 30 inch tall pots. Case studies are presented on the restoration of the cottonwood forests along the middle Rio Grande and Gila River and of montane riparian areas in the Apache-Sitgreaves National Forests.

Key Words

Plant materials, stock type, pole cuttings, tallpots, treepots, capillary fringe, water table, salinity, soil texture

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Properly functioning riparian areas serve key roles in providing fish and wildlife habitat, preserving water quality and water supply, and providing recreational opportunities. A comprehensive assessment of criteria useful in judging riparian area condition and attributes that constitute a proper functioning condition for lotic areas has been developed and refined by an interagency team (Prichard and others 1993; Prichard and others 1998). The team defined a properly functioning riparian area as having "adequate vegetation, land form, or woody debris" to "dissipate stream energy, filter sediment, aid ground-water recharge, aid in floodplain development, stabilize streambanks, and maintain channel characteristics." These functions of a riparian area "in accordance with its potential" should result in attributes including "channel stability, less erosion, good water quality, good water availability, forage, and fish and wildlife habitat."

The interagency team developed a checklist of attributes and processes dealing with hydrology, vegetation, erosion, and deposition (Prichard and others 1998). The hydrology attributes of a proper functioning riparian area include:

1) the floodplain is inundated relatively frequently;
2) beaver dams, if present, are active and stable;
3) dissipation of stream energy is controlled by sinuosity, width/depth ratio, and gradient consistent with the landform, geology, and bioclimatic region;
4) the riparian area should be widening or should have reached its maximum potential extent; and,
5) the condition of the upland watershed has not resulted in the degradation of the riparian area.

The vegetation attributes of a proper functioning riparian system include:

1) the age class distribution of the riparian plant community indicates the recruitment of young individuals and the maintenance of older individuals;
2) the species composition of the riparian area is diverse;
3) the characteristic soil moisture of a riparian-wetland area is indicated by the species present;
4) species with root masses capable of protecting against high flow events are present on the streambanks;
5) the condition of the riparian plant community is healthy and robust;
6) vegetative cover is sufficient to protect streambanks and dissipate energy during high flow events; and,
7) the riparian plant community can provide sufficient large woody debris to act as an agent to modify the hydrology if necessary for proper functioning.

The erosion and deposition attributes of a riparian area that is functioning properly include:

1) the energy of high flow events can be dissipated by floodplain and channel characteristics such as overflow channels and woody debris;
2) for channel types forming point bars, these point bars are being revegetated;
3) lateral movement of stream channel is associated with natural sinuosity;
4) channel lowering is not occurring at an unnatural rate; and,
5) excessive erosion or deposition is not occurring.

Natural Processes and Managed Activities Causing Degradation of Riparian Zones

The continuum of southwestern riparian zones from alpine to hot deserts are susceptible to an array of natural and human-generated processes that can degrade the proper functioning of these critical watershed areas. At lower elevations, agricultural development and flood control have imposed both structures and management resulting in severe disruptions of natural regeneration of the floodplain cottonwood forests. Dams have prevented or limited natural flooding which has eliminated the sediments and hydrologic regime required for the germination and establishment of the cottonwood and willow species that dominate the overstory in these forests. Levees have been constructed which constrain the floodplain extent and restrict the natural meanders of the river systems. Channeling streambeds to reduce flooding and increase water transport efficiency has resulted in human-dominated water conveyance systems. Drainage of riparian zones to create agricultural lands has altered shallow aquifers directly connected to rivers. River flow management prevents flooding and assures conveyance of water to downstream users. These hydrologic regimes have resulted in an artificial hydrographs unsuitable to the natural regeneration or maintenance of these cottonwood forests. The near complete loss of natural cottonwood regeneration has resulted in the invasion of exotic woody species, Russian-olive (*Elaeagnus angustifolia* L.) and saltcedar (*Tamarix ramosissima* Ledeb.), and the accumulation of enormous fuel loads, making these degraded riparian areas very susceptible to wildfire. These floodplain cottonwood forests do not contain fire-adapted native species as do some forestlands at higher elevations and thus little natural regeneration occurs after fire.

At higher elevations, catastrophic wildfires can result in direct destruction of riparian areas. Massive erosion and deposition of sediments resulting from wildfire in forested watersheds destroy fisheries and wildlife habitat, recreational facilities, roads, and water supplies for communities. Despite these deleterious effects, the results of wildfire can regenerate decadent riparian plant communities over time. The destruction of riparian vegetation directly by cattle and elk grazing has resulted in vast stretches of streams that do not support properly functioning ecosystem processes. Watersheds suffering from long-term overgrazing are more susceptible to extreme flood events resulting in accelerated rates of channel lowering. This landscape alteration can destroy and prevent the regeneration of riparian plant communities and concurrently increase sediment deposition in low gradient stretches and alter downstream riparian areas. Past logging practices involving poorly designed and sited roads and skid trails, as well as inadequate buffer zones surrounding streams, have contributed to the degradation of montane riparian plant communities. Historic trails that have become roads in the national forest system were developed with ease of access as the dominant feature, often resulting in roads dissecting riparian areas and perturbing stream courses. The recreational facilities in forestlands are generally situated streamside, resulting in intensive vehicle and foot traffic in the surrounding riparian areas.

The quantity, quality, and timing of water supply as well as wildlife and fishery habitat and recreational opportunities depend on the proper functioning of riparian plant communities. The many and varied natural processes and human controlled activities that are disrupting these critical riparian areas should serve as an impetus to preserve pristine stream systems and their accompanying riparian plant communities, as well as to develop cost effective restoration techniques. The discussion that follows will address the importance of species selection, techniques to propagate riparian plant materials, and the installation and maintenance of this planting stock to facilitate restoration of riparian zones. Case studies will address the riparian restoration practices employed in a number of southwestern ecosystems during the past decade.

Species Selection

The appropriate species to establish in degraded riparian zones may or may not be those present before the disturbance occurred. Some processes can alter the growing environment to such an extent that the pre-disturbance species are no longer suitable candidates. As an example, the imposition of flood control dams and managed flows can alter the salinity of soils by eliminating flooding. The effects of these water control structures and flow regimes on river hydrology and alluvial processes can modify the depth to ground water and the seasonal pattern of water table fluctuation. In such a case, the increased salinity may not allow establishment of the pre-disturbance species and a persistently deep water table may allow only certain planting stock types to be successfully used. In many instances, evaluation of plant communities in proper functioning riparian areas in the bioclimatic region will provide a guide to appropriate species.

General guidance as to appropriate species can be ascertained by site factors such as elevation and bio-climatic region. Dick-Peddie (1993) presents elevation ranges of greatest dominance for common riparian trees and shrubs in New Mexico (see Table 1). These elevation zones show the appreciable range where these species can dominate, taking into consideration the span of latitudes New Mexico covers.

An intensive study of willow (*Salix*) species on the Apache-Sitgreaves National Forests has determined the elevation range of occurrence on hundreds of sites on numerous watersheds between 5,500 and 10,000 feet (Granfelt 2001). This data has been summarized and analyzed (see Table 2) to provide average elevation, weighted average elevation based on number of sites, as well as minimum, maximum, mode, and number of sites where each species was found.

Bioclimatic or ecoregion can determine species suitability in addition to elevation and latitude. As examples, Arizona sycamore (*Platanus wrightii* S. Wats.) is only a dominant species at mid-elevations in southwest New Mexico and southeast Arizona; Arizona walnut (*Juglans major* (Torr.) Heller) can be a co-dominant species in southwest New Mexico mountains; little walnut (*Juglans microcarpa* Berl.) can be a co-dominant in southeast New Mexico (Dick-Peddie 1993).

Table 1. Elevation zones of greatest dominance of riparian trees and shrubs in New Mexico as presented by Dick-Peddie (1993).

Species	Common Name	Maximum Elevation (ft)	Minimum Elevation (ft)
Picea pungens Engelm.	blue spruce	10,700	8,200
Salix bebbiana Sarg.	Bebb willow	10,200	8,600
Populus tremuloides Michx.	quaking aspen	10,200	7,200
Alnus incana (L.) Moench ssp. *tenuifolia* (Nutt.) Breitung	thinleaf alder	9,500	8,000
Acer glabrum Torrey	Rocky Mountain maple	9,200	7,700
Cornus sericea L.	redosier dogwood	9,200	7,200
Acer grandidentatum Nutt.	bigtooth maple	9,400	6,900
Populus angustifolia James	narrowleaf cottonwood	9,300	6,300
Acer negundo L.	boxelder	8,300	5,900
Salix amygdaloides Anderss.	peachleaf willow	7,700	5,400
Salix irrorata Anderss.	bluestem (dewystem) willow	7,000	5,000
Alnus oblongifolia Torr.	Arizona alder	7,000	4,700
Populus x acuminata Rydb. (pro sp.) *[angustifolia x deltoides]*	lanceleaf cottonwood	6,800	4,700
Juglans major (Torr.) Heller	Arizona walnut	6,700	4,500
Populus fremontii S. Wats	Fremont cottonwood	6,600	4,700
Fraxinus velutina Torr.	velvet ash	6,500	3,800
Platanus wrightii S. Wats	Arizona sycamore	6,400	4,100
Sapindus saponaria L. var. *drummondii* (Hook. & Arn.) L. Benson	western soapberry	5,500	3,700
Celtis laevigata Willd. var. *reticulata* (Torr.) L. Benson	netleaf hackberry	5,100	3,300

Some of the species in Table 1 are obligate riparian species (for example, willows and cottonwoods); others are facultative or semi-riparian in that they often are found in upland areas. As examples, New Mexico locust (*Robinia neomexicana* Gray) and aspen (*Populus tremuloides* Michx.) are often found in montane riparian zones, but also form dense stands on mountain slopes after disturbance (Dick-Peddie 1993). Obligate species are not always found in typical streamside environments. As an example, in north-central New Mexico, narrowleaf cottonwood (*Populus angustifolia* James) has invaded mine overburden where the lack of competing vegetation, in part, allows soil moisture levels to build up sufficiently to support this species (Dreesen and Harrington 1999).

Closed basin riparian environments in the southwest such as alkali sinks or playas often have saline soils and support distinctive groups of species. Saline tolerant riparian species dominate such environments (Dick-Peddie 1993) and include such woody species as fourwing saltbush (*Atriplex canescens* (Pursh) Nutt.), pale wolfberry (*Lycium pallidum* Miers), and greasewood (*Sarcobatus vermiculatus* (Hook.) Torr.). Saline soils are also encountered in floodplain riparian areas especially those perturbed by flood control structures and flow management such as in the Middle Rio Grande Valley. Surveying sites before restoration activities should involve soil sampling (surface and

Table 2. Elevation zones of greatest dominance of riparian trees and shrubs in New Mexico as presented by Dick-Peddie (1993).

Salix Species	Minimum Elevation (ft)	Maximum Elevation (ft)	Average Elevation (ft)	Weighted Average Elevation (ft)	Mode Elevation (ft)	Number of Sites	Elevation Range (ft)
boothii Dorn	9250	9500	9375	9300	9250	6	9000-9500
arizonica Dorn	8500	9500	9000	9000	9000	5	8500-10000
monticola Bebb	7250	9500	8375	8800	9000	81	6900-9500
bebbiana Sarg.	6750	9500	8200	8800	8750	304	6000-10200
ligulifolia (Ball) Ball ex Schneid,	6250	8500	7475	7500	7500	85	3500-8900
irrorata Anderss.	5500	9000	7250	7475	7500	176	4500-9200
lucida Muhl. ssp. lasiandra (Benth.) E. Murr.	6000	8750	7350	7375	7500	78	3700-8300
exigua Nutt.	5500	8250	7075	7050	6750	89	1100-8500
lasiolepis Benth.	5500	7000	6250	6425	6500	39	3900-8000
laevigata Bebb.	5500	6750	6125	6325	6750	18	1700-6900
gooddingii Ball	5500	6750	6125	6025	6125	14	150-7500

subsurface) which can be a costly endeavor. Electromagnetic induction measurements can cost effectively indicate whether salinity levels throughout the soil profile are below threshold limits for establishment of Rio Grande cottonwood (*Populus deltoides* ssp. *wislizenii* (S. Wats.) Eckenw.) and Goodding's willow (*Salix gooddingii*) (Sheets and others 1994). High salinity in surface soils is not always an indicator of salinity problems throughout the soil profile; evaporation can concentrate salts as a surface crust. Proper species selection and planting stock type strongly influence revegetation success whether high salinity alluvium occurs only on the surface or not. In the Middle Rio Grande Valley, floodplain forest overstory components, Goodding's willow and Rio Grande cottonwood, have low salinity tolerance. In contrast, understory species such as fourwing saltbush, pale wolfberry, and screwbean mesquite (*Prosopis pubescens* Benth.) can tolerate appreciably higher soil salinity levels (Taylor and McDaniel 1998a; Taylor and McDaniel 1998b). If high salinity is a problem only as a surface crust and subsoil and groundwater salinity are not excessive, pole plantings of low tolerance species can be successful because adventitious root development occurs in a favorable environment.

Alluvium texture is of primary importance in determining suitable restoration species. Lotic systems with fast moving water deposit coarse alluvium of low fertility and high aeration. In contrast, lentic systems deposit fine alluvium (silts and clays) with higher fertility and less aeration. In general, lotic systems are conducive to the establishment of woody riparian trees and shrubs, while lentic systems are suitable for herbaceous wetland and marsh plants. Riparian areas which once supported woody species can evolve as the stream gradient declines, allowing the deposition of fine alluvium and the creation of conditions more suitable for wetland plants. Conversely, extreme flood events can alter low gradient stream sections to higher gradients, allowing coarse alluvium development leading eventually to a woody riparian habitat. Many failures of riparian restoration can be linked to errors in attempting to introduce woody species into lentic areas where only wetland herbaceous species will thrive.

The depth to ground water plays a key role in determining suitable riparian species. The primary rooting zone for obligate riparian plants is the capillary fringe above the water. The thickness of

the capillary fringe is affected by the alluvium texture, with finer textured alluvium having a broad zone of unsaturated soil with high moisture content. A thicker capillary fringe zone is advantageous in the sense of having greater water content per unit volume but is disadvantageous in the lower aeration resulting from less air-filled pores. The consequence of woody riparian species generally requiring highly aerated soils often leads to suitable restoration sites having a thin capillary fringe with lower water content but more air filled pores.

The fluctuation of ground water levels in riparian areas is dependent on the connection of the shallow aquifer to the stream; thus, as the stream water level changes the depth to ground water changes. Changes in stream level are reflected in an annual hydrograph of stream discharge whether controlled by natural processes or by human manipulation. The ground water fluctuations resulting from the variation in stream flow requires monitoring by shallow wells to determine the extent and timing of ground water level changes. This data is the basis for determining the planting stock type that will allow root access to the capillary fringe and provide a high potential for successful plant establishment. In addition, this data is needed in species selection because species vary in optimum depth to ground water. As an example, the pole planting prescription for Rio Grande cottonwood at the Bosque del Apache National Wildlife Refuge is a ground water depth between 6 and 12 ft (1.8 to 3.6 m). However, the prescription for Goodding's willow is 4 to 8 ft (1.2 to 2.4 m) (Taylor and McDaniel 1998).

Stream channel alteration by down-cutting coupled with lack of flooding due to water management structures has resulted in many riparian areas having such deep water tables and depleted near-surface soil water content that upland vegetation has invaded and proved much better adapted to the present hydrologic regime. In such situations, pole plantings may allow the establishment of riparian woody vegetation, but it is understood that such artificial regeneration will not create a self-perpetuating riparian plant community.

Riparian Plant Material Stock Types

As explained above, certain riparian situations will require specific stock types in order to optimize successful and cost-effective riparian restoration. In the Middle Rio Grande Valley and in many other low elevation cottonwood forest (bosque) environments, the depth to ground water over much of the historic floodplain is too great to permit the use of traditional stock types with shallow root systems without appreciable aftercare. One gallon treepot stock (4 in. x 4 in. x 14 in.) (10 cm x 10 cm x 36 cm) of riparian understory shrubs such as New Mexico olive (*Forestiera pubescens* Nutt. var. *pubescens*) and skunkbush sumac (*Rhus trilobata* Nutt.) planted in the bosque require several water applications per year for a few years to obtain acceptable survival rates. The expense in irrigating such out-plantings has prompted an emphasis on pole and whip plantings of large dormant cuttings and use of 30 in. (81 cm) tallpot containerized stock in such environments. Most cottonwoods and willows have good adventitious root development from large vigorous cuttings and have proved to be successfully established via pole plantings. Experimental field plantings and wildland plantings (Los Lunas Plant Materials Center 1994; Los Lunas Plant Materials Center 1998) have shown that other species outside the Salicaceae family have some promise as pole/whip cuttings. These understory species include seepwillow (*Baccharis salicifolia* (Ruiz & Pavon) Persoon in the Asteraceae), desert false indigo (*Amorpha fruticosa* L. in the Fabaceae), New Mexico olive (in the Oleaceae), and desert willow (*Chilopsis linearis* (Cav.) Sweet in the Bignoniaceae). None of these species have the fast growth rate of most cottonwoods and willows nor do they attain the ultimate size of cottonwoods or tree willows, thus pole production is not as rapid. In addition, these species appear to be more exacting in some cultural factors. These species do not appear to tolerate long storage periods in water as do pole cuttings taken from Salicaceae species.

Several species have been successfully established in riparian areas from rooted poles/whips (desert false indigo, New Mexico olive and desert willow). The rooted poles of these species as well as Arizona sycamore and Arizona alder (*Alnus*

oblongifolia Torr.) have been produced by mound layering techniques described in a later section.

The factors that promote the use of pole plantings to access deep soil moisture in the capillary fringe have prompted other planting stock alternatives other than pole/whip plantings. The improved out-planting success found with tall containers in desert situations (Bainbridge 1994; Bainbridge and others 1995; Miller and Holden 1992) implies that access to deep soil moisture or greater soil volumes may be enhancing plant establishment. The ability of riparian woody plant root systems grown in tall containers to quickly contact soil moisture in situations where the capillary fringe is deep should afford greater likelihood of survival and growth. Determining whether to use such an approach involves comparing the cost and effort of using cheap shallow containerized stock which are easily planted but will require supplemental water versus using more expensive deep stock types which are more difficult to grow and plant but require no aftercare.

Plant Material Production of Riparian Species

Pole Production Protocol

The current protocol for producing dormant pole cuttings of Rio Grande cottonwood, plains cottonwood (*Populus deltoides* ssp. *monilifera* (Ait.) Eckenw.), and narrowleaf cottonwood at the Los Lunas Plant Materials Center (LLPMC) is based on an evolution of cultural techniques developed through over 15 years of pole production experience. The optimum soil types for pole production are coarse textured (loamy sands to sandy loams) to provide high aeration potential; this also necessitates more frequent but lower irrigation volumes. Fields at the LLPMC are flood irrigated and are typically laser-leveled which allows uniform distribution of shallow depths of water. Most of the fields are 300 ft (91 m) in length from the irrigation riser to the distal end. The rows of trees are generally spaced at 10 ft (3 m) intervals. In order to facilitate later seedling planting, a single rip 18 in. (0.4 m) deep is formed along the intended planting line. A mulch-laying machine is used to put down 36 in. (91 cm) wide woven ground cover fabric (Dewitt Earthmat™) and to bury the fabric edges; the rip is centered as close as possible to the center of the mulch row. After securing the fabric ends in shallow trenches, holes for seedlings are formed at a spacing of 18 to 24 in. (0.4 to 0.6 m) using the flame from a propane-fired weed burner nozzle. By rapidly applying the flame to the desired planting location, a hole 3 to 4 in. (8 to 10 cm) in diameter is easily burned in the fabric by experienced personnel.

Planting usually occurs in June or July. Depending on the seedling container size and location of the rip versus the hole in the fabric, either dibbles or augers are used for planting. Generally, 10 $in.^3$ (164 ml) containers (Super Cell SC-10) can be dibbled, but larger diameter containers (for example, Deepot 16) require planting holes augered using 2 or 3 in. (5 to 8 cm) diameter bits powered by gasoline engines or electric drills powered by portable generators. A dose of 1 teaspoon (~6 g) of controlled release fertilizer (for example, Osmocote Plus or Sierra 3 to 4 month duration) is placed in the bottom of the dibbled or augered hole prior to planting. Containerized cottonwoods from seed collected at specific localities are generally used to maximize genetic diversity but maintain local ecotypes. Cutting-propagated stock can also be used if seed is unavailable, superior clones are desired, faster transplant production is required, or genetic diversity is not of primary importance. Seedlings are placed in the hole and back filling is accomplished by piling a small mound of loose soil around the base of each seedling with a shovel. Planting is done in the morning to allow sufficient time to flood irrigate the field the same day. The initial flood irrigation is sufficient to disintegrate the sandy soil mounds and fill any voids around the root balls. During the first several weeks after planting, the fields are flooded with 1 to 2 in. (2.5 to 5 cm) of water twice a week. After about the first month, watering intervals are lengthened to once a week. Because the LLPMC is situated in a cold desert climate with minimal winter precipitation, the fields are flood-irrigated at the end of the water season of our local irrigation district. In exceedingly dry winters, these fields can be flood-irrigated once or twice from irrigation wells. During the second growing season, the watering interval is increased to once every 2 weeks. Side dressing of nitrogen fertilizer (usually urea) is applied several times during the growing season. Phosphorus and potassium are banded adjacent to the edge of the mulch once a year. During subsequent years, the irrigation

interval can be lengthened to once every 3 weeks, but the fertilizer regime remains as stated above.

The harvest of poles can begin during the winter following the second field-growing season when pole lengths of 12 to 15 ft (3.7 to 4.6 m) can be achieved with butt diameters of 2 to 3 in. (5 to 8 cm). Typically, pole harvesting is initiated in January and extends until bud break (usually late March to early April). During pole harvest, side branches are pruned at the branch collar leaving only a few small branches at the top. The poles are bundled in groups of 5 with twine and transported to a staging area where the butt ends are placed in water tanks to assure maximum hydration before transporting and planting.

The initial pole harvest from a field involves severing the single stem at 4 to 6 in. (10 to 15 cm) above the ground. The following growing season this stump will sprout numerous stems, some reaching 6 to 8 ft (1.8 to 2.4 m) in the first year and producing pole-size stems after one to two additional years. The stumps with numerous stems are pruned in the late fall and winter to reduce the number of stems to the 5 to 6 most vigorous vertical stems.

Mound Layering to Produce Rooted Poles/Whips

A number of riparian species that can not be established from traditional dormant pole cuttings might be established from a rooted pole cutting. One technique to produce large rooted cuttings is mound layering. Two methods of mound layering have been investigated at the LLPMC: an intensive method and a low resource input method.

The intensive system has been tested with Arizona sycamore and Arizona alder. This alder species is a poor producer of adventitious roots under conventional vegetative propagation conditions; however, this sycamore species is capable of modest rooting success and possibly might be established via traditional pole plantings. The intensive system is described in detail in the propagation protocol available on the Native Plants Network (Anonymous 2000) and in Dreesen and Harrington (1997). In summary, a bottomless inverted nursery container is placed over an established plant in the nursery during the winter. The container is filled with a soil-less media and outfitted with micro-sprinklers (for example, Roberts Spot-Spitters®). The media is top-dressed with controlled release fertilizer in the spring. The large rooted and etiolated stems of Arizona sycamore produced by this technique had 100% and 73% survival, respectively, 3 months after transplanting into large containers.

The low input method makes use of a bottomless inverted container, but in this case the established plants are in flood irrigated fields. The containers are filled with field soil and watered strictly by precipitation and upward capillary movement when the field is flood irrigated. The year following mound formation, the stems are harvested for planting as rooted poles. The initial field trial comparing rooted versus non-rooted poles showed survival percentages for desert false indigo of 93% versus 50%, New Mexico olive of 100% versus 60%, and desert willow of 50% versus 17% (Los Lunas Plant Materials Center 1996).

Production of Cuttings and Seed of Montane Species in a Cold Desert Environment

The LLPMC is situated at an elevation of 4800 feet where the hot Chihuahuan Desert converges with the cold deserts of the Four Corners region. This cold desert environment experiences daily maximum temperatures exceeding 100 °F (38 °C) in summer and winter lows typically in the teens. The soils and waters are fairly alkaline. The establishment of stock plants of montane riparian species for seed and cutting production was needed to avoid the cost of travel for propagule collection, to avoid the possibility of finding no acceptable propagules, and to attempt to ensure vigorous stock plants by proper irrigation and fertilization. Early attempts with several montane willows (*Salix irrorata* Anderss. and *Salix monticola* Bebb) planted in sandy flood-irrigated fields were unsuccessful. The next approach involved planting in organic–rich beds. Trenches 18 in. (0.5 m) wide, 24 in. (0.6 m) deep, and 20 ft (6 m) long were excavated with a backhoe. These trenches were filled with potting soil reclaimed from pots with dead plants which had been stockpiled for a year; the mix contained variable proportions of spaghnum peat moss, composted pine bark, perlite, and pumice. One-gallon treepot stock plants from cuttings or seed were transplanted into these beds. The beds are irrigated with micro-sprinklers (for example, Roberts Spot-Spitters®).

Fertilization usually involves controlled release fertilizer top-dressing with a dose appropriate for the size of the stock plant. Sulfur is top-dressed each year to counteract the alkalinity of the irrigation water. Several montane species have thrived in these beds and yielded the following propagules: bluestem willow (*Salix irrorata*) seed and cuttings, blue elderberry (*Sambucus nigra* L. ssp. *cerulea* (Raf.) R. Bolli) seed, red-osier dogwood (*Cornus sericea* L.) seed and cuttings, littleleaf mock orange (*Philadelphus microphyllus* Gray) seed, smooth sumac (*Rhus glabra* L.) seed, and park willow (*Salix monticola)* cuttings.

Vegetative Propagation of Large Containerized Riparian Plants

Forest disturbances, mentioned previously, have resulted in many montane riparian forest communities lacking adequate vegetation to ensure proper riparian function. Many of these montane riparian systems are located in narrow, steep drainages from foothill locations up to alpine regions. Efforts in the past to use techniques developed for lower elevation have proved to be ineffective both from a cost standpoint as well as an ecosystem restoration tool. The difficult access to many of these areas by large equipment significantly reduces the feasibility of using dormant poles. Rapidly dropping water tables also restrict the suitability of smaller container or bare-root planting stock. However, large (one-gallon and bigger) containerized stock types have worked consistently in many trials. The advent of new container configurations (for example, Steuwe & Sons, Inc. Tree Pot™) has allowed for the development of more effective stock types for these types of plantings. The narrower and deeper pot designs generate a deeper root system, allowing transplants in a montane riparian planting environment to maintain contact with the capillary fringe for a longer period of time than is the case with shallower and wider stock types with the same root volume. These stock types can be planted using hand tools, thereby eliminating the need for large equipment that is required to install large, dormant poles.

The Mora Research Center has established many cottonwood and willow riparian species native to the southwest using the larger container systems. Vegetative propagation has used stem cuttings ranging 1 to 3 cm in diameter and 40 to 60 cm long. No use of exogenous plant growth regulators has been required to achieve acceptable rooting percentages (> 90%) during the past three years of trials. The pot system we have been testing has been the Steuwe & Sons Inc. 1-gallon "Tall One." In preliminary trials, we examined several media types containing various ratios of peat, perlite, vermiculite, and sand. Nursery growth and one-year survival observations indicate no differences between media in either growth or survival. However, from a management perspective, the media mixes containing sand were considerably heavier and more difficult to transport and plant. Subsequent trials and operational production has used a 2:1:1 mixture of peat:perlite:vermiculite. A slow release fertilizer, Osmocote 14-14-14, 3 to 4 month, is incorporated into the media at a rate of 1kg per cubic meter. We have found in preliminary trials that coating the interior of the pots with a copper containing root pruning compound (Spin Out®), improves the growth of the plants considerably (Harrington and Dreesen 2001, unpublished data).

Cuttings are collected in late winter to early spring while the cuttings are dormant. If necessary, the cuttings are stored under refrigerated conditions until needed. When ready, the stem cuttings are pushed into pots containing media until just the upper 10 to 20 cm (or approximately 3 leaf nodes) remain above the media. Cuttings are irrigated on an as needed basis. A typical initial irrigation regime would water the containers once every five days. Once root initiation and shoot growth has commenced the irrigation frequency increases to once every two or three days. At the end of the production regime, containers are usually being irrigated once a day. Typical production duration is 12 to 14 weeks. We have found irrigating with micro-emitters in each pot is effective in both irrigating the plant and reducing labor costs associated with irrigation. Current production of this stock type is exclusively outdoors. We have found over the past several years that adequately sized plants can be achieved in outdoor production. Final plant size is dependent on the species being planted with the cottonwoods and large willow species capable of producing shoots of one to two meters in height. Some of the smaller shrub-form willows may achieve final shoot height of only 70 to 150 cm in this production system.

Special Seed Propagation Techniques

Collection, Cleaning, and Sowing of Cottonwood and Willow Seed

Cottonwoods and willows are dominant woody species in riparian areas in many ecoregions. Although propagation of most *Populus* and *Salix* species (exceptions *P. tremuloides* and *S. scouleriana* Barratt ex Hook.) by vegetative (stem) cuttings is a traditional technique, there are situations when seed propagation may be desirable for reasons of genetic diversity or limited vigorous cutting stock availability. Seed can be obtained from the wild if collectors can be on site during the brief period immediately before seed dissemination. At the LLPMC, seed of both *Salix scouleriana* and *Salix irrorata* have been collected from stock plants propagated from non-juvenile cuttings. In the case of *Salix scouleriana*, seed produced stock plants can bear seed within 4 to 5 years. Catkin collection is typically planned to coincide with the appearance of cotton emerging from the partially open capsules (Schreiner 1974). With small seed lots, willow catkins can be harvested and placed in paper bags to trap seed released as capsules open during drying (several days at room temperature).

Salix seed can be cleaned using a methodology similar to that described by Schreiner (1974) for *Populus* seed using an air stream and soil screens. A compressed air source and a set of soil screens in a series from top to bottom of 250 m, 500 m, 125 m are employed; the seed and catkins are placed between the 250 m and 500 m screens. A jet of compressed air is blown through the top screen in a swirling fashion; the seed is dislodged and remains on the 125 m screen with the cotton and empty catkins remaining in the 500 m screen. We have tried a similar approach using screens with larger openings for Rio Grande and plains cottonwood with little success. The technique presently used involves drying the cottonwood catkins in porous fiber bags for several days and then hammer-milling the capsules and seed at 600 rpm with no air suction and using a $^1/_8$" exit screen. The resulting mixture of seed, cotton, and broken capsules is cleaned with a two screen seed cleaner (#8 upper screen and a $^1/_{16}$" lower screen) with very low airflow. A number of successive passes through the seed cleaner will result in little inert material remaining in the seedlot. Both *Populus* and *Salix* seed are sown within a few days after cleaning before viability declines significantly. The seed of willow is typically sown in plug trays with no covering while cottonwood seed can be sown in final containers (for example, SC-10) or plug cells with a light covering. The surface must be kept continuously moist; germination of willow seed is often apparent after two days. Thinning of seedlings will be required and is usually performed in the final containers after the seedlings are of sufficient size to make clipping feasible.

Wet Tumbling Seed Treatment

One unconventional seed treatment applied at the LLPMC involves tumbling seed in water, or wet tumbling. Dry tumbling of seed has been one approach for seed scarification that has been investigated (Dreesen and Harrington 1997; Bonner and others 1974). The objective of wet tumbling can also involve scarification if an abrasive is incorporated in seed/water slurry. The addition of gravel and water facilitates abrasion due to the force imparted to the grit by the tumbling gravel. The size of gravel used is typically several times the diameter of the seed being treated. The grit can be a carborundum material used for rock polishing or a sharp sand. Although this treatment method may effect some seed coat degradation, other effects may be more important, such assuring complete imbibition in well-aerated water and the leaching of water soluble germination inhibitors in the seed coat. A typical treatment would involve wet tumbling for several days to a week with daily changes of water.

For a few species, this treatment appears to be a practical substitute for cold stratification. Two currant species (*Ribes aureum* Pursh. and *Ribes cereum* Douglas) and pale wolfberry have required 2 to 3 months of cold stratification to achieve acceptable germination in past trials. Wet tumbling followed by one to two weeks of after-ripening in a warm moist environment has resulted in germination without cold stratification. The dry seed of another important riparian species, red-osier dogwood, has required one hour scarification in concentrated sulfuric acid and then 2 to 3 months of cold stratification for acceptable germination. Using newly picked fruit, rapid germination has been achieved by wet tumbling the fruit with $^1/_2$ to $^3/_4$ in. (1 to 2 cm) gravel. Most of the pulp is removed in the first day of tumbling and separated by screening and float/sink manipulations in water. After pulp removal, the seed is wet tumbled for several more days with

daily water changes. The imbibed seed is then after-ripened and initial germination starts in about 7 to 10 days and continues for several weeks. Although a limited number of species have been tested with wet tumbling, many additional species may benefit from this treatment.

Standard Containerized Seedling Production Procedures

The most common containerized stock type we have employed for riparian restoration is a one-gallon treepot. In montane situations, this container size is generally adequate for acceptable rates of survival with little aftercare except protection from herbivores such as cattle and elk. As described above, in lower elevation cottonwood forests, understory shrubs planted as one-gallon treepot stock typically require supplemental watering for the first few years to become established. The routine propagation methodology employed at the Los Lunas Plant Materials Center is outlined below:

Stock Type: One gallon treepot, 4"x4"x14"

Target Root System: Consolidated root mass sufficient to prevent root ball disintegration during out-planting

Propagation Environment: Greenhouse 70 °F (21 °C) day, 55 °F (13 °C) night during winter, maximum summer temperature 85 °F (29 °C). A watering bench with mini-sprinklers automatically waters plug trays once a day in early morning. The watering bench is covered with a copper-coated fabric (Texel Tex-R® Forestry fabric) to reduce root egress from the plug cells; this fabric covers a filter fabric (Dewitt soil separator fabric) which acts to pull excess water out of plug cells via capillary water movement.

Plug Tray Seeding: Dry or pretreated seed (for example, wet tumbled, dry tumbled, acid scarified, or hydrogen peroxide soaked) are sown in plug flats with square deep cells (288 or 512 cells per flat). Media is a commercial soilless mix (Sunshine #1); plug trays are loosely filled with dry to slightly moist media, leveled off, and then lightly compressed with an empty plug tray. The number of seed sown depends on size and estimated germination. Small or fluffy seed are dispersed as evenly as possible. Larger and more easily handled seed are sown with a goal of 2 to 5 seed per cell. Very small seed is not covered if its size will allow the seed to be washed into the media with overhead sprinkling. Larger seed with a possible light requirement are lightly covered with perlite. Fluffy seed receive a light covering of media enough to provide contact between seed and the moist plug media. Larger seed is covered with 2 to 5 mm of media.

Cold Stratification: Those species which require cold stratification are typically sown in plug trays as described above and placed on the watering bench for several days to ensure that the media is thoroughly moist and seed are imbibed. The seeded plug flats are covered with an inverted empty plug flat to allow the 4 to 5 seeded flats to be stacked with the inverted flats acting as spacers. These stacked flats are placed in clean or disinfected polyethylene bags (in other words, re-used soil-less media bags) and are sealed with twist-ties; these bags contain perforations punched by the media manufacturer that allow some air exchange. These bagged plug tray stacks are placed in a walk-in cooler held at 40 °F (4 °C) and periodically checked for signs of germination or the necessity for adding moisture. When germination has started or when a sufficient stratification period has passed, the plug flats are moved to the greenhouse and placed on the watering bench.

Intermediate Container Type and Volume: Ray Leach Super Cell – 10 $in.^3$ (164 ml) volume, 1.5 in. (3.8 cm) diameter, and 8.25 in. (21 cm) depth.

Growing Media: Mix of 2 parts Sunshine #1 or #2 with 1 part perlite. six lb (2.7 kg) of controlled release fertilizer (CRF) Osmocote Plus 15-9-12 incorporated per cubic yard (765 l) of mix. For plants started in the greenhouse during winter, 8 to 9 month release CRF is used, but for spring grown material, 3 to 4 month release CRF is used.

Production Time in Intermediate Container: The time required to produce a seedling ready for transplanting into a one-gallon tree pot is very dependent on species and the time of year in the greenhouse. Fast growing species like most riparian species can be ready in 3 to 4 months from germination. Slow growing species can take over a year.

Planting Technique: The filled Super Cells are dibbled to provide a hole for the plug seedling. The plug seedling root ball is removed using a flat powder spatula with a blade about 6 mm wide and 30 mm long attached to a handle. The blade is plunged along the side of root ball and the seedling plug is levered out of the cell. The plug is dropped into the dibbled hole and the media is pressed around the root ball with fingers. Top watering firms and fills any voids around the plug. If excessive numbers of seed have germinated, excess seedlings can be cut off during the plug transplanting process or later after the seedlings are well rooted.

Establishment Phase: The Super Cell seedlings in the greenhouse are watered with soluble fertilizer at every other watering. The fertilizer solution is Peters Peat Lite Special 20-10-20 at a rate of 200 mg/l nitrogen. Thinning of seedlings down to one per container can occur during this phase, usually when the seedlings are 2 to 4 cm tall.

Rapid Growth Phase: Fertigation continues as described above.

Hardening Phase: The goal is to have the Super Cell seedlings ready to move outside in early May after the last freeze but before excessively hot outdoor temperatures. In the outdoor nursery, larger seedlings may require watering every day, smaller seedlings generally every other day. The seedlings are fertigated about once a week with Peters Peat Lite Special 20-10-20 at a rate of 200 mg/l nitrogen.

Final Container Type and Volume: One gallon treepot, 4"x4"x14" (10 cm x 10 cm x 36 cm), 173 in^3 (2.83 l) volume.

Growing Media: Commercial nursery canning mix of aged screened softwood bark, pumice, and sphagnum peat moss.

Total Time in Final Container: The fastest growing species, like most riparian species, can be ready in one year after transplanting, if transplanting occurs in May. The slowest growing species can take 3 or more years.

Planting Technique: The treepots are filled with media and dibbled with a Super Cell planting dibble. Controlled release fertilizer (CRF) is top-dressed at planting or soon thereafter. Osmocote Plus and Sierra CRF have been used. For pots transplanted in late spring, a 5 to 6 month delivery CRF is used. Seedlings transplanted later in the summer receive a 3 to 4 month delivery CRF. The treepots are supported in cages 36 in. x 36 in. x 8 in. tall (91 cm x 91 cm x 20 cm) constructed of 4 in. x 4 in (10 cm x 10 cm) wire mesh fencing; each cage holds 81 pots.

Establishment Phase: Watering frequency in this phase in usually three times a week for riparian species. Plants are typically grown without shade.

Rapid Growth Phase: Watering frequency can be as often as every day for very large riparian plants with substantial leaf areas.

Hardening Phase: The watering frequency is reduced in late September to early October to promote hardening-off. The treepot cages are surrounded by straw bales before winter to lessen temperature fluctuations and provide some insulation for the root systems.

Tallpot Production Methods

The Los Lunas Plant Materials Center has developed a specific pot configuration that helps solve some difficulties found with earlier tallpot designs such as weight, pot materials expense, and plant removal and planting. The pots are constructed of 4 in. (10 cm) diameter PVC thin walled sewer pipe. The 30 in. (76 cm) sections (1/4 of the standard 120 in. pipe length) are split lengthwise on opposite sides for about 27 in. (69 cm) with the top of the pipe remaining intact to maintain the pot as one piece. Nesting one side of the split pot into the other side tapers the pot; this taper is maintained with 3 or 4 wraps of 0.5 in. (1.3 cm) filament tape along the length of the pot. The split sides and taper make it easier to remove the root ball and the splits provide 2 slots that help to prevent root spiraling and provide increased aeration. The bottom of the split wrapped pipe is covered with a 6 in. x 6 in. (15 cm x 15 cm) piece of needlepunched non-woven copper-coated fabric (Texel Tex-R® Forestry fabric) and attached with a cross of filament tape and an additional circumferential wrap. The copper hydroxide coating is oriented toward the inside of the pot to limit root egress. Capillary connection is maintained between the fabric pot bottom and the ground cover fabric in order to

prevent a perched saturated zone in the bottom of the tallpot.

A standard nursery mix (composted pine bark, pumice, and peat) is used to plant containerized seedlings. One-gallon tree pots have been transplanted into the tallpots; some of the root mass has to be removed from the corners of the root ball to allow placement and back-filling. Smaller containerized stock is also used for potting up: Super Cells (10 in^3, 164 ml), Deepots D16 (16 in^3, 262 ml), Deepots D40 (40 in^3, 656 ml), and treebands (3 in. x 3 in. x 9 in.). Controlled release fertilizer (3 to 4 month delivery) at rate of 15 to 20 g is generally top-dressed after transplanting. The initial method of supporting the pots involved stands constructed from 4 in. x 4 in. wire mesh 36 in. wide (10 cm x 10 cm mesh 91 cm wide) sandwiched horizontally between straw bales. Groups of tallpots are enclosed by straw bales to moderate pot temperature during summer and winter. The short life of the bales resulting from decomposition has prompted a new strategy for maintaining tallpots. The latest method involves a 32 in. (81 cm) high enclosure constructed of 6 in. (15 cm) tongue and groove concrete block ("speed-block") with 12 in tall 4 in. x 4 in. (30 cm tall 10 cm x 10 cm) wire mesh cages inside the enclosure to support the individual tallpots. The blocks are filled with sandy soil and the outside is lined with straw bales for insulation. Species with fast growth rates can be ready for outplanting one year after transplanting from one gallon tree pots into tall pots and can be ready in two years after transplanting from smaller containers.

Planting Procedures for Diverse Stock Types of Riparian Species

Planting of Dormant Pole Cuttings and Whips

Various types of equipment have been employed for drilling holes for pole plantings ranging from hand-operated bucket augers with 8 ft (2.4 m) handles to large truck mounted augers typically used for power pole installation. The LLPMC has been using one type of auger for 8 years. A four-wheel drive farm tractor outfitted with a front-end loader has been adapted by replacing the loader bucket with a hydraulically powered auger head and an 8 ft (2.4 m) long 9 in. (23 cm) diameter bit with full flighting. The principal circumstance where this drilling approach has been unsuccessful is in dry sands or in cobbly alluvium where the hole frequently collapses. Trial and error probing of riparian zones will usually provide locations where the alluvial conditions allow full depth holes to be completed into the water table. When back-filling holes after pole placement, a tree guard 5 ft (1.5 m) tall and 18 in. (46 cm) in diameter constructed from poultry wire is inserted partially into the hole to anchor the tree guard. A team of 4 people (one equipment operator; two people planting poles, back-filling, and installing guards; and, one person supplying poles and guards) can install 35 poles per hour.

The tool used for planting coyote willow (*Salix exigua* Nutt.) whips is an electric spline drive rotary hammer that can accommodate a 1 in. (2.5 cm) diameter 36 in. (91 cm) long carbide-tipped bit. Coyote willow is planted where ground water is shallow so this tool provides a hole into the ground water or into the capillary fringe. The rotary hammers are especially useful when frozen soils are encountered which happens often during the late winter/early spring planting period. A portable generator is required capable of starting and running the 9 amp rotary hammer motor. A team of 4 people (2 drilling and 2 planting) can install 200 whips per hour.

If proper alluvial conditions are encountered, appropriate planting procedures are followed, and after-planting care is used, success rates around 90% at 5 years after planting can be achieved. Coarse alluvium with low salinity capable of supporting a hole into the water table is required to maximize success. If extreme fluctuations in ground water level are expected, the pole needs to be planted below the water table to ensure that the capillary fringe will surround the butt end of the pole during periods of maximum ground water depth. Planting requirements include a dormant vigorous large diameter cutting of sufficient length to extend into the water table and leave a substantial aboveground stem (at least 5 ft (1.5 m)). The cuttings should be kept well hydrated during storage and transport. Aftercare including tree guards (poultry wire cylinders) to protect from beavers and control of defoliating insects (for example, cottonwood leaf beetle (*Chrysomela scripta*)) will improve establishment success if these pests are present in significant numbers. Exclosures to prevent domestic livestock and elk

browsing of pole plantings are also required in situations where browsing pressure is substantial.

Planting Willows and Cottonwoods in One-Gallon Treepots in Montane Riparian Areas

The treepot stock type is conducive to planting with hand tools such as shovels or post hole diggers. Smaller, powered equipment such as back pack or wagon mounted augers are also effective. The most appropriate tool depends on a number of factors including the number of units to plant, access to the planting site and the planting site itself. Outplanting success is highly dependent on several site factors. First, as is the case with most riparian plantings, the root system must be planted well into the capillary fringe zone in order for adequate new root growth and establishment to occur. We have found that coordinating planting with spring snow-melt often achieves the best results. A second site factor is providing protection following planting. Domestic livestock and/or elk and deer have damaged many trial plantings. Fencing or another form of protection is essential to ensure planting success. Finally, following the same guidelines associated with planting smaller forestation stock (in other words minimizing the amount of root pruning; not leaving an exposed root ball on the surface, etc.) will contribute to better survival rates.

Planting Methods for 30 inch Tallpots

The auger used for pole planting (8 ft (2.4 m) long, 9 in. (23 cm) diameter bit) is also used for 30 in. (76 cm) tallpot installation. As with pole planting, the hole is drilled to the water table, but loose soil is removed only from the top 30 in. (0.8m). This full depth hole penetrates any hardpan or other alluvial layers that might restrict root penetration into the capillary fringe. Most riparian woody species form well consolidated root balls if sufficient production time is available. The root ball can be slid out of the pot after the tape and fabric bottom are removed. If the plant has an immature root system, the tape wraps and fabric bottom can be removed, and then the plant in the pot is placed in the planting hole. The pipe can be slowly lifted from the root ball while simultaneously back-filling the hole to prevent the disintegration of the root mass. If the plant canopy is too large to fit through the top of the pot, the slots can be extended so that the pot is split into two sections. Tree guards can be installed when back-filling if beaver or rabbit damage is expected. A team of 4 people can install 10 to 15 plants per hour.

In upland situations or where ground water is very deep, supplemental water may be required to enable establishment. The LLPMC has been testing the use of watering tubes to provide deep pipe irrigation. This approach has proven to be a highly successful irrigation method in desert environments (Bainbridge and others 2001). One watering tube design uses a 3 in. (7.6 cm) PVC sewer pipe cut into lengths of 30 in. (76 cm) and 10 in. (25 cm). The bottom half of the 30 in. (76 cm) section has transverse slot perforations cut in opposite sides of the pipe. The 10 in. (25 cm) section is joined to the 30 in. (76 cm) section with a coupler that is held by friction (not cemented). This configuration allows the top portion of the pipe above ground to be removed when the watering tube is no longer needed. The buried bottom section is left in place to prevent root disturbance and is back-filled with soil. When in use, the watering tube is capped to prevent evaporation and animal entry. This design is costly in terms of materials and labor for fabrication. Another more cost-effective design was developed making use of heavy weight plastic seedling protection tubes (Protex Pro/Gro Tubes) 24 in. (61 cm) in length. Bottomless one gallon treepots are inserted (friction fit) in each end of the tube to extend its length and provide additional rigidity to prevent tube collapse during back filling. The bottom treepot ends up in an inverted position when installed. An inverted 3.5" square pot is inserted inside the top treepot to serve as a cap.

The 9 in. (23 cm) diameter hole provides sufficient space for the tallpot root mass as well as the watering tube for deep pipe irrigation. At the time of planting, water is applied to the soil surface to aid in filling backfill voids as well as providing near surface moisture. The watering tubes are filled with water at planting to charge deep soil moisture. Trials with starch-based water absorbent polymers have been conducted to determine whether the slow release of water in the tubes is superior to water alone. It is anticipated that one or two water applications per year for a few years using deep pipe irrigation may be sufficient to provide high rates of establishment depending on precipitation timing and amounts.

Riparian Restoration in the Middle Rio Grande Valley

As described in the introduction, the riparian zone in the Middle Rio Grande Valley suffers many assaults on its biological integrity. Flood control structures and flow management regimes have prevented natural flooding necessary for cottonwood and willow regeneration. These activities have also resulted in the buildup of salts in the former floodplain. Exotic woody species have invaded vast stretches of the floodplain which were cottonwood forests historically. These exotics have also magnified the potential of severe wildland fires near urban corridors because of the massive fuel loads produced by these noxious invaders.

Some of the most successful projects in removing one of the primary exotics, saltcedar, have been conducted at the Bosque del Apache National Wildlife Refuge. Mechanical removal uses a three-step process of aerial stem removal, root plowing, and root raking at a total cost of about $1,500/ha (McDaniel and Taylor 1999). The second control approach involves aerial application of herbicide (imazapyr plus glyphosate) followed by prescribed burning of dead standing saltcedar at a total cost of about $300/ha (McDaniel and Taylor 1999).

Bosque del Apache National Wildlife Refuge used pole plantings of Rio Grande cottonwood and Goodding's willow in their early restoration efforts following saltcedar control (Taylor and McDaniel 1998b). Later investigation proved that natural recruitment was possible subsequent to over-bank flooding during peak river flows in late May and early June; regeneration was greatest in sand deposits resulting from secondary channel development (Taylor and others 1999). Large areas of historic floodplain at the Refuge were later restored using controlled flooding of land cleared of saltcedar; careful management of declining water levels in impoundments after flooding allowed establishment of a predominance of cottonwoods and willows and little saltcedar.

Other approaches to simulate natural regeneration have examined the use of micro-irrigation on historic floodplain sites that no longer experience natural flooding (Dreesen and others 1999). Maintenance of high surface soil moisture during seed dissemination, germination, and early growth stages of Rio Grande cottonwood has resulted in successful establishment. Micro-irrigation frequency is decreased and water depth application is increased gradually for several years until roots access the capillary fringe above the natural water table and the riparian vegetation is self-sufficient.

Planting along the Santa Fe River near Cochiti Pueblo

A section of the Santa Fe River within Cochiti Pueblo land is a perennial stream fed by springs and possibly seepage from Cochiti Lake. This riparian zone had been severely degraded by cattle grazing for decades prior to 1994. The Pueblo constructed fenced exclosures at 3 sites along the stream in 1993. The LLPMC installed 1250 Rio Grande cottonwood, lanceleaf cottonwood (*Populus x acuminata* Rydb. (pro sp.) [*angustifolia x deltoides*]), and Goodding's willow poles in February 1994. At the three sites, the capillary fringe was encountered in all augered holes, but ground water was not encountered in any holes at the maximum auger depth of 8 ft (2.4 m). During the first growing season, the plantings suffered severe defoliation from a cottonwood leaf beetle infestation that affected long term survival. After 4 growing seasons, the survival of Rio Grande cottonwood accessions ranged from 42% to 85% and Goodding's willow ranged from 60% to 76% (Los Lunas Plant Materials Center 1997). Poles planted close to the stream have annual height growth of about 6 ft (1.8 m). After 4 growing seasons, these trees had heights approaching 30 ft (9 m) and calipers exceeding 10 in. (25 cm). The poles planted farthest from the stream have survived but put on little growth.

Riparian Mitigation on the Corrales Reach of the Rio Grande

Riparian restoration studies were conducted on the Rio Grande north of Albuquerque as part of a Army Corps of Engineers project mitigating disturbance of riparian vegetation resulting from the rebuilding of 10 miles of levees. The Los Lunas Plant Materials Center installed approximately 18,000 pole and whip cuttings in 1997 and 1998. Cottonwood survival averaged 85% after the first growing season when data from all accessions were pooled. On those sites with a shallow water table (3 to 5 feet, 0.9 m to 1.5 m) and soils with sufficient cohesion to allow holes to be drilled to ground water, cottonwood survival was 98% after one year and 92% to 95%

after two years (Los Lunas Plant Materials Center 1998). On those sites with dry gravelly sands, the holes collapsed preventing the pole from being placed into ground water; cottonwood survival ranged from 65% to 79% after one year. Goodding's willow survival was 87% on good sites after two growing seasons. On poor sites, survival ranged from 48% to 72% at the end of the first growing season.

The average survival of poles of New Mexico olive, desert false indigo, and seepwillow were 70%, 60% and 52%, respectively, after 2 years. Survival ranged from 30% to 84% on the various sites when data for these 3 species are pooled. This variability probably resulted from differing soil conditions among sites as well as inconsistent pole hydration periods for different lots of poles. Coyote willow planted using rotary hammers at one site had survival percentages of 99% after 2 years. Because the coyote willows were densely planted (about one foot apart), the whips were not protected from beaver at one site, with the result of total decapitation of over 5000 willow whips. Subsequently, these willows vigorously re-sprouted, probably as result of carbohydrate reserves stored in the 3 ft (0.9 m) stem section planted below ground.

New Mexico olives in one gallon treepots were planted at site with a water table depth of 4 to 5 feet (1.2 to 1.5 m) in October 1996 and 1998. A portion of the plants was planted under the canopy of the cottonwood gallery forest. The transplants were surface watered several times during the initial fall and again the next year. Survival after 2 years under the cottonwood canopy was 85% (Los Lunas Plant Materials Center 1998).

Riparian Restoration within the Southwest Region's National Forests

Gila River Bird Area Stream Bank Stabilization Project

The Silver City Ranger District on the Gila National Forest initiated a project in 1991 to stabilize stream banks on the Gila River which had experienced severe erosion during high peak flows because woody vegetation had been removed so the floodplain could be farmed. Over one and half miles of streambanks were stabilized. The slope of the cut bank was reduced to less than 45 degrees. A temporary berm was constructed between the active channel and the cut bank and alluvial material was removed to reduce the depth to the water table. Over 10,000 poles (primarily Fremont cottonwood (*Populus fremontii* S. Wats) and Goodding's willow) were planted. In addition, one half mile of abandoned irrigation ditches were re-hydrated and planted with approximately 2,300 boxelder (*Acer negundo* L.). The emphasis on boxelder results from this species being the preferred nesting tree in this area for the endangered southwestern willow flycatcher. The positive results of this restoration project have been the renewal of a degraded streambank riparian forest, the stabilization of streambanks, and the movement of wildlife back into this riparian area, including the southwestern willow flycatcher.

Riparian Restoration Experience on the Apache-Sitgreaves National Forests

Livestock Management and Exclosure Fencing

Riparian restoration has been emphasized for the last 12 years on the Apache-Sitgreaves National Forests of Arizona. Primarily, riparian improvement has been accomplished through improved livestock grazing plans. These plans include exclusion of use in sensitive areas, while other areas are monitored closely and stock is rotated out as soon as utilization levels are achieved. Due to a high degree of elk utilization early in spring, livestock may not be allowed onto certain areas at all during some years. Plantings of riparian species have been successful only in areas that are fenced to exclude all large ungulates including elk. Numerous elk exclosure fences have been installed on the Forest both in riparian areas and in areas targeting aspen reproduction. Most of these fences consist of 8 ft (2.4 m) tall hogwire (two 4 ft (1.2 m) sections) attached to 12 ft (3.6 m) T-posts, but some electric fence has been used to keep elk out during the growing season. Damage to fencing by animals is inevitable and continual maintenance is necessary to keep it intact. Electric fencing is effective, but has led to entanglement and death of a few elk trying to jump the fence. Much of the electric fencing is being replaced with hogwire or woven wire fencing. Hogwire fenced areas have also been jumped, usually from the tops of hardened snowdrifts, resulting in these elk

being held inside the exclosure until a gate can be opened and the animals herded out.

Objectives of Riparian Plantings

Several objectives have been considered with plantings of riparian species on the Apache-Sitgreaves National Forest. The primary objective has been to restore woody species to riparian areas that for one reason or another have lost them. Such plantings can never restore the full diversity or number of plants present originally, but they can restore a self-sustaining island of plants that provide a seed source, which hopefully will help colonize adjacent areas within the drainage. In places, plantings of riparian woody species can be used in conjunction with bioengineering techniques to help stabilize stream banks. These areas are normally very limited in size and do not entail whole stream reaches. Another common use for riparian woody species is in limited areas that may require riparian plants more from an aesthetic need rather than driven by ecological function. Woody riparian species often provide ample shade and are closely tied to numerous recreational values associated with riparian areas. Lastly, outplantings of artificially propagated plants that are either rare or threatened or endangered species may help sustain such species until they can again become self sufficient and reproduce on their own. In the past, limited attempts to reproduce Arizona willow (*Salix arizonica* Dorn) on the Forest have had very modest successes, but part of the reason for failures may have been tied to planting into unsuitable ecological settings. Thorough knowledge of ecological requirements is needed to replenish threatened and endangered species, but such critical information is usually lacking or, at best, scanty.

Planting Techniques

Depending on the application or purpose of various plantings, different techniques have been used with varying success. Riparian plantings have been successfully combined with bioengineering techniques to stabilize eroding stream banks. In one case, long willow cuttings (*S. monticola, Salix geyeriana* Anderss., and *Salix irrorata*) were incorporated into log cribs to help tie loose soils together and also prevent elk from pulling the cuttings out of the cribbing. This planting technique worked fairly well and resulted in dense clusters of willows growing out of the front side of nearly vertical crib walls. Elk browsing did occur, but did not significantly damage the structure. Willow fascines have also been tried along creek side, but a combination of factors reduced their effectiveness. Quite often, volunteer groups who enjoy cooler weather in Arizona's higher elevations, especially during summer, do such work. This season unfortunately does not coincide with the best time to transplant cuttings, as they are not dormant and are often in full leaf or in flower. This significantly contributes to a lower success rate.

Massive plantings of willow cuttings have been successfully installed in late fall. In order to help stabilize a stream bank with a small adjacent floodplain, a massive number of dormant cuttings were planted nearly horizontally at creek side. A small bulldozer was used to cut a gently sloping shelf into a raw bank at creek side. The shelf was slightly higher at creek side than against the bank by about 1 to 2 ft (0.3 to 0.6 m). The long cuttings were then laid out onto the shelf at a rate of about 10 per lineal foot (33 per m), allowing about the top 2 to 3 ft (0.6 to 0.9 m) to protrude beyond the shelf out over the creek. The remaining 4 to 6 ft (1.2 to 1.8 m) of the cuttings were then buried by the bulldozer while simultaneously cutting the bank down to a manageable slope. This approach allowed the branch tips to be exposed, while the long buried sections could grow roots. The sloping shelf also allowed the cuttings to be installed so that the butt ends were lower than the tips. The elevation of the shelf was within the capillary fringe of the sandy-loam soils, which kept the cuttings moist but not wet. The active channel of this small stream was vegetated with sedges and rushes, pointing to saturated soil conditions, which willows cannot tolerate. Planting only in the capillary zone avoids excessive moisture and anaerobic soil conditions. This planting technique restored a long section of stream bank with relatively little hand labor, and resulted in nearly 100% survival and establishment of cuttings. The project was put to the test the following spring when an unusually high flow passed through the area during snowmelt. It survived with minimal damage. Similar near-horizontal willow plantings have been successfully installed in a number of locations on the Forest in the fall. One area entailed planting a fill slope below a parking lot in a busy recreation area near a lake. The cuttings were inserted into small shelves opened in the slope with a backhoe, then back-filled and

compacted. The cuttings survived over-wintering well and grew into healthy shrubs, which stabilized the fill slope, provided screening of the parking lot from view, and discouraged visitors from descending the slope instead of using the stairway.

Live staking has been successfully implemented in several areas both in spring and fall using narrowleaf cottonwood. Stakes were made from large stems about 2 in. (5 cm) diameter and 1 to 1.5 ft (0.3 to 0.5 m) long, cut at an angle on the bottom and straight on the top. These were driven into soft soils along stream banks with hand sledges and left to sprout. Success rates varied by area, some survived nearly 100%, others about 10%. Lower success rates were usually associated with areas that dried out excessively during summer. Narrowleaf cottonwood has also been successfully established from 4 to 5 ft (1.2 to 1.5 m) long poles. These were planted with all their branches intact in 2 to 3 ft (0.6 to 0.9 m) deep auger holes during spring while buds were still dormant. Other areas were planted with 6 to 8 ft (1.8 to 2.4 m) long dormant poles planted into a long trenches excavated with a backhoe. These trees survived relatively well provided they remained moist. Ephemeral washes can be challenging to plant. Wet years may induce planting too high on the banks to keep them out of saturated soils, while dry years may result in planting them within the active channel which then scours out the plantings. Several years of plantings may be required to establish a desired quantity of plants in such an area.

Riparian Soil Considerations

It cannot be emphasized enough that various riparian species require specific soil conditions and will not survive if planted into unsuitable conditions. As mentioned earlier in this paper, most soil limitations are intimately associated with aeration. Fine-grained sediments only provide limited aeration, but will draw capillary moisture to higher elevations above the water table. This allows some leeway in selecting planting sites for woody species requiring aerated soils by planting further away from active channels or perhaps higher up on the banks. Too often we see well-meaning volunteers planting willow or cottonwood cuttings into streambanks of saturated wet meadows, where success rates for woody species are near zero. The challenge in coarser grained soils is to plant in areas that maintain moisture but are not saturated. However, soils made of coarse alluvial sands and gravels only provide a very narrow band of capillary moisture, which risks either drought conditions or saturation with a small change in water table elevation. Saturated soils lack sufficient aeration and quickly turn anaerobic. Generally, anaerobic conditions are more often encountered in finer-grained soils. Coarse-grained soils maintain aeration through higher permeability rates that allows better gas exchange, and ground water also tends to mix with aerated surface waters to maintain a limited level of oxygenation.

Summary

Site assessment examining such factors as water table depth and fluctuation, soil texture, soil salinity, and browsing pressure from livestock and wildlife is a prerequisite to successful riparian restoration. These factors, along with elevation and ecoregion considerations, will aid in the selection of appropriate restoration species. A number of plant material stock types and planting techniques are available to land managers challenged with restoring riparian areas in the Southwest. Stock types such as pole cuttings and tallpots offer opportunities to accomplish cost-effective establishment in demanding low elevation riparian environments. Larger containerized materials and unconventional methods of outplanting cuttings offer the potential for increased restoration success in montane environments.

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OUTPLANTING LONG TUBES WITH THE EXPANDABLE STINGER: A NEW TREATMENT FOR RIPARIAN RESTORATION

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Abstract

Long tubes are a new stock type developed specifically for restoration of challenging sites such as disturbed riparian areas. Constructed out of polyvinyl chloride plastic pipe, long tubes have a Vexar lining to promote good root growth and easier extraction. The expandable stinger is a new invention that was developed to outplant long tubes. The stinger is attached to an excavator, which hydraulically operates a metal beak that holds the long tubes in place while they are planted. The expandable stinger has been used to plant stream gravel bars and road cut and fill slopes, but has other potential applications.

Key Words

Nursery, seedling, propagation, cutting, container

Restoration of riparian areas is receiving increasing interest in recent years. But these sites present unique challenges. Besides a wide variety of soils and topography, riparian zones are unique in that their hydrologic condition does change rapidly. Streamside plants can be inundated by brief flood events and then the water table in the soil can drop rapidly. In addition, the erosive power of floods can dislodge newly established plants.

There are two different categories of plant materials used in riparian revegetation: 1) dormant, nonrooted hardwood cuttings used in bioengineering applications; and 2) live plants used for a variety of other purposes (Hoag and Landis 1999). Container or bareroot plants add diversity to the riparian revegetation area by ensuring the establishment of species that do not root readily from woody cuttings. However, standard nursery stock types have limitations. The root systems of even the largest bareroot or container seedlings are not deep enough to initially withstand the erosive forces of floods and then stay in contact with groundwater during the summer. Recently, nurseries have begun experimenting with larger stock types that will meet the challenges of riparian restoration. For example, the "Tall One" TreePot™ has a capacity of 173 in^3 (2,835 cm^3) and a root system that is 18 in. (46 cm) deep. What about a container that has a root system that is even deeper?

THE LONG TUBE STOCKTYPE

Long tubes consist of a 3 in. (7.6 cm) PVC pipe that is lined with Vexar® tubing (Figure 1). The pipe can be cut to any depth, depending on the project objectives, plant species selection and factors on the outplanting site. Typically, long tube containers are cut at 6 inch increments: 12, 18, and 24 in. (30, 46, and 61 cm). A 24 in. (61 cm) long tube is comparable in volume to a one-gallon (3,785 cm^3) container. Vexar tubing is cut to lengths longer than the PVC pipe to allow at least 3 in. (7.6 cm) or more netting to extend above the pipe. The extended netting can either be folded

down over the pipe or kept upright to protect plants from browsing. Vexar tubing is specially ordered from the manufacturer to be made of biodegradable plastic so that it will break down in the soil after outplanting. The tubes are filled with growing media consisting of 50% vermiculite and 50% *Sphagnum* peat moss. A similar stocktype using a 6 in. diameter by 30 in. long (15 x 76 cm) PVC pipe, without the Vexar tubing, was reported to successfully restore native desert plants to the Joshua Tree National Monument in Southern California (Miller and Holden 1992).



Figure 1. Long tube seedlings are constructed from sections of plastic pipe with a Vexar lining.

Advantages of the Long Tube

1. Greater root depth. From late spring to early fall, rainfall is low for much of the western United States and most soils dry out by mid summer. Riparian areas are no exception, as soils can dry to a depth of several feet by mid summer. After outplanting, long tube seedlings have the advantage of beginning root growth at much deeper soil depths during the first growing season. This allows roots greater access to either the water table or soils with higher moisture levels.
2. High root surface area. Long tubes have a high root surface area, which can be an advantage to early seedling establishment. Comparing the 24-in. (61 cm) long tube to other one-gallon (3,785 cm^3) containers, the long tube has twice the root surface area as the round one-gallon container and a third more than the "Tall One" Treepot™ container. This greater surface area creates more root-soil contact, resulting in potentially greater root egress into the native soil during initial establishment.
3. Easy to extract. The original reason for placing Vexar netting within the PVC pipe was to protect roots and stem from animal damage. A more important reason for using this material is because it holds the growing media together to allow easy and complete extraction without damage to the seedling. Seedlings would be hard to extract from the long tubes because of their weight and the high surface area. Without the Vexar, seedlings would have to be pulled from their container by the stem, which can result in physical injury. With long tube containers, this stress is eliminated because seedlings are extracted by pulling the Vexar netting. This makes it possible to extract long tube seedlings at any time. Most container seedlings can only be extracted late in the growing season after a firm root plug has developed. Unfortunately, this firm root plug often becomes root-bound and prevents good root egress after outplanting. The netting in the long tube gives the client a greater outplanting window and more flexibility in planning.
4. Eliminates root spiraling. The Vexar lining in the long tube also has another benefit. In round containers with smooth walls, roots grow in a spiral pattern. However, in long tubes, new roots follow the diamond-shaped pattern of the Vexar to the bottom of the container where they are air-pruned. This effectively prevents root spiraling and results in a better root system after outplanting.

Although long tube seedlings less than 24 inches can be planted by shovel or power auger on deep soils with few rocks, these soil types are rarely found in riparian areas in mountainous terrain. Recently, a planting device called the expandable stinger (US Patent 6,158,362 with additional patents pending) was invented to plant long tube seedlings or non-rooted cuttings of *Salix* and *Populus* in soils with high rock content. Attached to the arm of an excavator (Figure 2), the expandable

THE EXPANDABLE STINGER

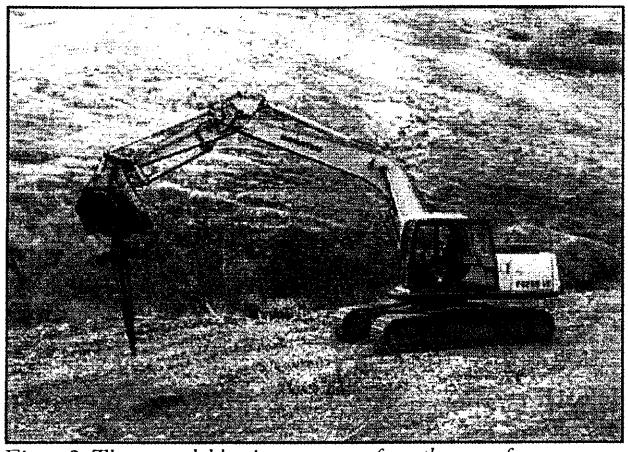


Figure 2. The expandable stinger operates from the arm of an excavator and can plant seedlings or unrooted cuttings in rocky soils or heavy brush.

stinger is hydraulically operated and can plant seedlings or cuttings in any soil type or slope gradient. The expandable stinger is composed of two parallel steel shafts, which are narrowed to a point at the end to form a "beak" (see figure 3A). The shafts are hinged in the middle so that they open and close in a scissor-like manner. Each half of the beak is formed to create a long hollow chamber in the middle when they are closed.

On the outplanting site, a long tube seedling or non-rooted cutting is inserted into the beak. The expandable stinger is then maneuvered to the planting spot, where the beak is inserted into the soil (Figure 3B). The beak is opened allowing the seedling to drop to the bottom of the created hole. While the beak is open, the stinger is lifted from the soil leaving the seedling in place (Figure 3C). On sandy or coarse textured soils, the sides of the hole will collapse on the plug, forming a good soil contact. Other soil types and soil conditions might require manually tamping the soil around the plug. Ideally, long tube containers are planted several inches below ground line.

The expandable stinger can plant seedlings and non-rooted cuttings at a rate of one to five per minute depending on planting density, soil type, site accessibility and degree of planning. Generally, planting rates decrease on rocky soils and steeper slopes and increase where planting densities are high and travel time from one planting area to another is minimal. Having a supply of seedlings or cuttings at the site and ready for planting increases

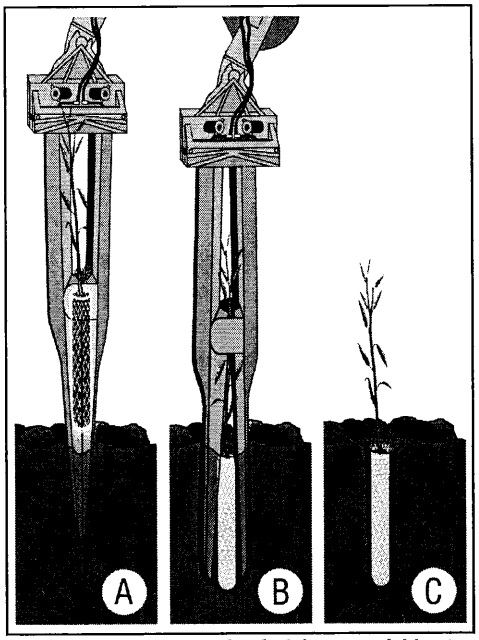


Figure 3. The beak-like head of the expandable stinger holds the seedling or cutting in place (A), while hydraulically opening a hole in the soil (B). When the beak is opened and the head removed, the seedling is successfully planted (C).

efficiency. However, this can be a challenge due to the large size and weight of these containers. Due to the inaccessibility of many sites to trucks, other methods of seedling transportation have been developed, such as using a trailer attached to an all-terrain vehicle.

Applications

The long tube stocktype and the expandable stinger expand the possibilities for riparian restoration. These areas include:

1. Gravel bars along streams. Gravel bars can stay barren for years because the high surface rock prevents seed germination and seedling establishment. While these sites look inhospitable, there is available moisture held within the gravel matrix, which can be accessed by roots of long tubes.
2. Steep slopes. Steep slopes along road cuts and fills revegetate slowly because seedling establishment is curtailed due to soil raveling. Planting a long tube seedling can shortcut the difficult early establishment phase of seedling development.
3. Invasive plants. On many streams, the riparian areas are overgrown with aggressive, undesirable vegetation, like the Himalayan

blackberry (*Rubus parviflorus*). This species can form a blanket of vegetation that is impenetrable to planting or the establishment of more desirable species. The expandable stinger can reach into these inhospitable sites and plant larger seedlings that can compete with the existing vegetation.

4. Road decommissioning. Another potential application would be to plant large seedlings in the middle of roads that are being taken out of service. This quick and effective visual screen discourages trespass and accelerates tree and shrub establishment.

Limitations

The expandable stinger is restricted to those sites accessible to an excavator. The main limitation is that, for safe operation, the steepness of slope must be less than 40 percent gradient. The size of the excavator also determines the planting radius: smaller excavators can reach 20 feet while the larger machines reach 50 feet.

A potential limitation to the long tube is the decomposition rate of the Vexar tubing. Although the tubing is composed of biodegradable plastic, it is unclear how fast this material breaks down in different soil types and moisture regimes.

Field Trials

The long tube stocktype and the expandable stinger have been in use for three years in eastern Washington and parts of Oregon. It was first used in the Aostin Creek Watershed, a 325 square mile watershed in the in the Blue Mountains of southeastern Washington to restore the loss of riparian vegetation resulting from winter floods. Over 50,000 long tubes and non-rooted cuttings of cottonwoods, willows and ponderosa pines were planted with the expandable stinger on newly created gravel bars, sites that were considered manually unplantable. At the end of the first year, survival was found to be greater than 80 percent (Johnson 2000).

In spring of 2001, a Federal Highway Administration project in the coast range of southwestern Oregon was planted with ponderosa pine, big leaf maple, willows and ash. Steep, rocky cut and fill slopes were planted with long tubes using the stinger. Most of these sites were not accessible to planters due to the steep slope gradients. Initial establishment of all species was greater than 90 percent.

Conclusions

The long tube is a new stock type that has a root system that extends deep enough to assure establishment on these harsh sites. The expandable stinger is an effective and efficient method of planting long tubes. Although this outplanting system would be too expensive for typical planting projects, planting long tubes with the expandable stinger offers an innovative solution to many harsh sites such as disturbed riparian zones and road cuts and fills.

Acknowledgements

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RESTORATION OF RIPARIAN AREAS WITHIN THE MEGRAM FIRE

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Abstract

A variety of treatments have been employed to restore riparian areas affected by wildland fire on the Six Rivers National Forest in northwestern California. The Megram Fire began as a series of lightning strikes on August 23, 1999, eventually burning 125,040 acres. Specific treatments have included contour felling of dead trees, straw mulching, placement of straw wattles, helicopter seeding of non-native, non-persistent barley, planting trees and shrubs, and introducing and/or reconfiguring woody debris designed to enhance stream channel stability. In addition, lessons learned from several riparian restoration projects implemented in non fire-affected areas can be applied to fire rehabilitation efforts.

Key Words

Fire rehabilitation, anadromous fish, aerial seeding, contour felling, planting, mycorrhizae

Large-scale wildland fire events have the potential to impair water quality, especially in those areas where precipitation comes mainly in the form of rain, rather than snow. Declining salmon and steelhead populations in the Pacific Northwest have prompted land managers to hasten the post-fire recovery process by employing a variety of rehabilitation methods.

What came to be known as the Megram Fire began as a series of lightning strikes on August 23, 1999. Then, two separate fires—Megram and Fawn—joined together during the second week of September.

The fire began in the Trinity Alps Wilderness of Shasta-Trinity National Forest in northwestern California and entered Six Rivers National Forest (SRNF) on September 18, 1999. The fire was declared controlled on November 4, 1999—after burning 125,040 acres. As luck—or lack thereof—would have it, portions of the fire burned into extensive blowdown created by a windstorm that occurred nearly four years earlier. This event uprooted several thousand acres, creating a fuel load and fire hazard of 300 to 400 tons per acre.

OBJECTIVES

The objective of fieldwork conducted during the spring following the fire was to ground-truth fire severity rankings derived from aerial photographs and, if necessary, to prescribe appropriate treatments. Fieldwork indicated that widespread tree mortality had created an increase in water yield, initiating surface flow at many sites where, previously, only subsurface flow had occurred. At this time (spring 2000) neither widespread stump sprouting of brush or tree species nor the establishment of understory forbs had occurred. As a result, a moderate amount of erosion was taking place at certain sites in non-cohesive, decomposed granite soils.

METHODS

During the Burned Area Emergency Rehabilitation efforts immediately following the fire, several straw bale check dams were built to trap sediment. Prior to prescribing additional similar treatments, we conducted a field review of

these structures the following spring with a team of earth scientists from the USFS Pacific Southwest Research Laboratory. It was their opinion that the amount of sediment saved per structure did not warrant the effort.

Treatments

So, within riparian areas, three specific treatment measures were employed to keep soil in place.

1. Aerial seeding: 2,490 acres were seeded with barley (at an application rate of 100 lbs/acre). Topographical slopes within the fire area averaged between 50% to 60%. Although riparian areas weren't specifically targeted, germination was excellent in riparian areas, due to seed "bounce and roll." As expected, about 20% of the barley re-seeded one year after the seeding project.
2. Contour felling: Much of the fire occurred in areas dominated by large, old-growth Douglas-fir and white fir. Some of these logs already on the ground were re-positioned along topographical contours to serve as "catches" for sediment and seeds. Many of the fallen dead trees were hung up on one or both ends, remaining above the ground, both in riparian and upslope areas. These "spanners" were "bucked out"—cut in lengths from 10 to 20' and re-positioned on the ground. Other seeding projects have shown that the presence of flat areas for seeds to "catch" on greatly enhances results, especially in areas with greater than 50% slope.
3. Tree and shrub planting: Because of the increase in water yield the first spring following the fire, some of the draws in the fire area were planted with phreatophytes—species not previously present there. It is our belief that these seedlings will become established before the water yield returns to normal.

Species

Specific plant species used were:

Sitka alder: Forest assistant Botanist John McRae collected 0.25 lbs. of Sitka alder (*Alnus viridis* ssp. *sinuata*) seed from riparian areas within the Megam fire during April 2000. This would have produced 10,000 plants at the expected germination rate of 30% to 40%.

The seed was given to Tsemeta Nursery (operated by the Hoopa tribe), located in northwestern California. Seeds were sown May 2000; a germination rate of 30% to 40% was achieved. However, the presence of root maggots reduced the number of plants suitable for delivery to 4,000. Seven acres of riparian areas were planted (at a spacing of 8 to 9 feet).

American dogwood: Cuttings from *Cornus sericea* were collected within the fire area, albeit prior to the fire, as part of a road decommissioning project. Cutting survival was 82%, rivaling the success rate of willow from the same project, at 91% survival.

McRae collected 10 lbs. of seeds of this species during the spring following the Megram fire. After one year of freezer storage, the germination rate was 30% to 40%. Therefore, for those species capable of rooting, the question arises: would it be best to grow out from seed or merely collect cuttings? Personally, I'm in favor of going with cuttings, if sufficient personnel can be mobilized at the appropriate times. It's been my experience that the Forest Service procurement process often proves too cumbersome for the complicated "dance" of seed collection, storage, stratification, scarification, grow out, and transport back to the site for—finally—planting.

Deerbrush: During spring 2000, 10,000 deerbrush (*Ceanothus integerrimus*) seedlings were planted within the fire area (headwaters of East Fork Horse Linto and Cedar Creek), albeit not restricted to riparian corridors.

Another erosion control treatment that we employed in the Megram fire area was mulching of 1,186 acres with 19,000 bales of rice straw, although this activity was limited to upslope areas. Concern over the potential importation of noxious weeds has prompted SRNF to specify certified weed-free or rice straw on its mulching projects.

We also used a limited number of straw wattles: "straw sausages" encased in a plastic mesh covering. This product accomplishes the same thing as contour-fallen trees. Advantages are that they conform to irregular topography better than trees and are easily carried by two people. However, in areas where an adequate supply of dead timber already exists, it's difficult to justify their use given their cost and the logistics involved in hiking them into the project site. In addition, if

portions of the wattle are allowed to drag on the ground during their transportation to the site, the mesh can break, greatly reducing their life expectancy.

Results and Discussion

In those streams draining the fire area, turbidity showed little increase above pre-fire levels during the first two winters following the fire. In addition, the placement of several sediment fences revealed a lack of soil displacement. The lack of soil loss was due to precipitation (100% and 50% of normal, respectively) and treatments that included aerial seeding, the placement of straw mulch, contour felling and bucking of trees, and the planting of trees and shrubs.

We've been using commercially available mycorrhizal fungi for two years on several landslide revegetation projects. Unfortunately, on one project, the monitoring plot was located within a landslide planting area that has since moved downslope. However, the Chico Tree Improvement Center has used Bio-grow, a product available from Mycorrhizal Applications located in Grant's Pass, Oregon. The control group of seedlings (no mycorrhizal fungi applied) had 95% mortality from a damping-off from *Fusarium* root rot. Meanwhile, the plants that were inoculated with the product experienced a 95% survival rate while in the nursery.

This product comes in two forms: tablet and liquid. The tablet is buried in the ground near the roots. It contains 5 kinds of mycorrhizal fungi, IBA (a rooting hormone) and folic acid, etc. The tablet is the size of a Bayer aspirin. Cost: $39.95/1,000, minimum order is 2,000 tablets. The product is for conifers. For field plantings, this method is recommended rather than the liquid.

The liquid form, termed "Bio-grow," comes as a 1 liter liquid. It contains essentially the same ingredients as the tablets. Prior to application, the liquid is diluted at a rate of 1:100. The 1 liter container treats 15,000 square feet. It is important to get the ingredients to the roots, so it shouldn't be applied during dry season. The product is basically for conifers. Cost: $69.95/liter, minimum order of 2 liters.

Several lessons that we've learned from riparian restoration projects conducted outside of fire-affected areas can also be applied to fire rehab efforts.

Riparian Projects

General Notes

Other riparian plant species that have performed well in SRNF restoration projects include bigleaf maple, red and white alder, black cottonwood, and various species of willows.

For those species that are capable of rooting from cuttings—mainly willow and cottonwood—the debate continues on whether to use cuttings or previously rooted stock. On Six Rivers, we've used both, with a mixed bag of results. Two case studies follow.

Todd Ranch Riparian Revegetation Project

The restoration site is along the South Fork, an undammed tributary to the Trinity River. Approximately 600 cuttings (300 each willow and cottonwood) were collected and planted during February 1998. Survival following 3 growing seasons is 55%. We were able to tap into a domestic water system to drip irrigate the cuttings, the tallest of which are now greater than 25'.

Herbaceous plants, grass, or brush can outcompete recently planted seedlings and cuttings. In addition, browsing by deer, rabbits, or wood rats can be a problem. The following summarizes our experience.

During Phase II of a riparian revegetation project, we purchased VisPore Tree mats (3' x 3' polyethylene fabric mats) from Treessentials of St. Paul, Minnesota. Their literature stressed that not all mats are created alike. Namely, their product contains 400 Microfunnels per square inch: four times the number of any other mat—or so they claimed. These holes are small enough to suppress weeds, yet sufficiently porous to admit water. Despite considerable grass at the restoration site, we were quite pleased with the mat's performance. However, with any new product, when evaluating product literature, it's often difficult to separate hyperbole from actual on-the-ground performance.

In this case, the company spoke the truth. For the previous year, when funding was tight, our silviculture department loaned us their mats. They were pleased with the performance of the mats

they'd used the previous year. However, while soliciting bids for future work, our procurement department got involved, insisting—yes, you knew this was coming—on going with the low bidder. Several dozen dead trees later, we confirmed that the mats were essentially impermeable. Therefore, especially on the steeper sites, both drip irrigation and rainwater flowed off, not through, the mat. Although water never reached developing cutting roots—boy, did it enhance grass growth at the margins of the mats.

Treesentials also sells Supertube treeshelters: thin-walled, translucent fiberglass tubes designed to thwart browsing deer, rabbits, or rodents. This 4-inch-diameter product comes in 1-foot increments, from 2 to 5' long. We used a control group of plants to monitor the performance of the tubes. Our experience was much like that of those customers mentioned in their brochure: considerably faster growth rates. However, prodigious growth rates from all our cottonwood cuttings required the removal of all tubes by mid-May of the first year. This product may prove valuable for those tree species with slower growth rates and/or the presence of more browsers, but we discontinued their use.

Horse Linto Creek Revegetation Project

This project employed the use of 6-month-old rooted cuttings, grown in super cells. This method of culture had a major shortcoming: the meager amount of rooting medium fell away from the fragile roots. In the end, it was impossible to justify the amount of time and energy and money spent to have the cuttings grown out.

Planting unrooted cuttings is justified if the following conditions can be met: the site is no more than 3 to 10' above the water table or the site can be irrigated. Timing is key. In our area, we have a relatively narrow window to collect cuttings from dormant plants, say January and February, which may or may not dovetail with the Ranger's plans for the fire crew.

We have a project now in the planning stages where we expect to borrow techniques employed by our colleagues who restore gravel pits in the foothills of the Sierras. At such sites, they collect cottonwood poles 2 to 4" in diameter, 4 to 12' long. Holes are dug by backhoe; the depth of the planted poles ensures access to groundwater without the need for irrigation.

Summary

Not all land managers agree that fire rehabilitation efforts should be attempted following large wildland fires. Nor is there consensus among those in favor of such activities as to the appropriate scope of rehabilitation efforts. Given the potential for soil loss following catastrophic fires, there is an increasing interest in protecting habitats for fish populations listed as threatened under the Endangered Species Act—or otherwise declining.

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NURSERY PRACTICES IN TENNESSEE

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Key Words

Bareroot nursery, conifer production, hardwood production

Tennessee is a hardwood state; 87% of the state's 13,000,000 forested acres are hardwood. The remaining 13% are Pine or Mixed Hardwood-Pine forest types. There are approximately 1,000,000 more forested acres today that there were in 1950. Most of this increase is related to abandoned hillside farmland.

Tennessee has two nurseries: one near Jackson in West Tennessee; the other in Tennessee's southeastern most county, near Chattanooga. Between the two, 25,000,000 conifer and 3,500,000 deciduous 1-0 bareroot seedlings are grown. The East Tennessee Nursery near Chattanooga grows the conifers while the West Tennessee Nursery grows the deciduous seedlings.

Deciduous seedling sales the last five-year have been very good. Reforestation deciduous seedling sales have increased from 500,000 in 1995 to 2,500,000 in FY 2000. Non-reforestation deciduous seedlings have remained at less than 500,000 during the same period.

This increase in deciduous seedling sales is due to high stumpage prices during this period. As stumpage increases, reforestation interest increases. Water quality concerns are another reason for the increase in deciduous seedling demand. Carbon sequestration has had a positive impact. One individual last week ordered $100,000 worth of hardwood seedlings for this purpose. Federal wetland reclamation programs are still another reason for the increase.

HARDWOOD SOWING AND CULTURING

Our hardwood seedlings are generally fall sown. The first step is to level the ground prior to bed building. The second step is to broadcast-sow grass (wheat, rye or oats) at two bushels per acre. The third step is the bed building. It covers the grass seed while preparing the ground to be sown with tree seed. Using the hardwood sower developed and built on site ("nutty buddy"), hardwood seed is sown in four drills. The grass germinates and forms a mat which provides the following: over-winter bed stabilization, bed insulation, squirrel barrier, crow barrier, spring mulch.



Figure 1. Nuttall oak seedlings at 2 days.



Figure 2. Grass three weeks after sowing. Seedlings present, but cannot be seen.

The grass is oversprayed with Roundup on February 15 the following spring. This kills the grass in anticipation of March germination. We usually use a 2% Roundup solution at 30 gallons per acre.

The "nutty buddy" is a ground driven machine. Four rotating disks turn through the seed hopper retrieving and sowing seed. The chain drive that turns these disks has interchangeable sprockets with which we can alter sowing density. The rotating disks are interchangeable to allow the use of different sized disks for different sized seed.

Conifer Sowing and Culturing

We use two sowers for our pine seedlings. The Oyjord® sower sows eight "single rows" per bed. The Summit precision sower sows eight "double rows" per bed. The precision sower is characteristically slower than the Oyjord®. We use it for our higher germination seed and, as time allows during our sowing window, our lower germination seed. As the sowing window closes, we will use the Oyjord® sower.

The precision sower allows us to sow at approximately 20% greater density, produces less than 1% cull, and provides a very uniform crop.

The last two years, we have experimented with the use of live grass (wheat, rye, and oats) as mulch on our spring sown pine crop. Pine bark mini-nuggets have traditionally been used. But this year, we used it on only 50% of our pine crop. The other 50% was sown using the live grass as mulch. We initially used grass for the following reasons:

1) Grass is less expensive. Mulch at $13/yd results in a $30,000 annual cost, while grass at $5/bushel at 2 bushels/acre results in a $400 annual cost.
2) Grass is easier to apply. Mulch requires a manure spreader crossing each bed, having to be refilled every other bed. Grass, sown before the beds are made, uses a very fast broadcast sower and requires fewer refills.

The grass germinates before the pine seed and we let them grow in tandem until the grass starts to drape over the seedlings. Poast® readily kills the rye and oats. Wheat seems to be more difficult to kill and it wasn't until we applied Goal that we had a burn that killed the wheat. Last year, we experimented with six beds allowing the grass to drape over the seedlings for about a month longer than we otherwise would have before we applied a pesticide. On three other beds, we did not kill the grass at all. The seedlings finished the year on all nine beds with no obvious negative effect on seedling quality or quantity. This year (2001), the dead grass continues to stabilize the beds and provide a thatch-like mulch. We observed that seedlings growing amidst the live grass were more vibrant and just as developed as same aged seedlings growing in traditional pine bark mini-nugget mulch.



Figure 3. Top pruned loblolly pine at 10 weeks in bark mulch.



Figure 4. Loblolly seedlings emerging through deadened grass mulch (seven weeks old).

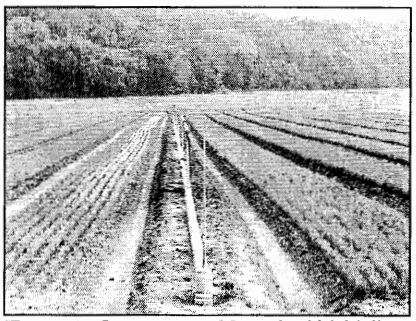


Figure 5. Comparison of 9 week old loblolly mulch regimes. Grass on left, bark on right (same density per regime). Loblolly (Grass Mulch) appears to be 7 to 10 days behind Loblolly (Bark Mulch).

There were several unanticipated positive and negative findings in using grass as mulch for pine culturing.

Positive results of grass mulch

- The grass provided a lateral shade for the seedlings that seemed to be beneficial.
- We had no trouble with mulch floating away.
- The grass helped to retard weed growth.
- The grass will emerge through a Goal pre-emergent treatment (2 qt/a) but is greatly diminished (more plant vigor than density of grass stems). An alternative might be to plant more than 2 bushels per acre.
- The thatch that resulted from the dead grass made a good mulch that has lasted well past crown closure.
- Of the three grasses (wheat, rye, and oats) used in the spring sowing of pines, all provided the desired results but the wheat seemed harder to kill with Poast®.
- Our survey of mulch versus grass inside the same seedlot resulted in the same bed density.
- An observation from our use of the grass approach last year found that the quality of the seedlings at the time of lifting was identical under both mulching regimes.

Negative results of grass mulch

- As of July 26, 2001, the "grass" seedlings appeared to be approximately 10 to 14 days behind the mulch seedlings in development. We theorize that the decomposition of the grass root system has made nitrogen less available to the seedlings.

Changes in the Nursery

It was interesting to me to consider the things that have changed in the last five years at our nursery.

In the last year, we have incorporated a "run-off" management system. In consultation with the NRCS and the Tennessee Valley Authority, we have built three ponds connected to each other and to lagoons, all for the purpose of catching and filtering runoff from our beds.

In terms of actual nursery operations and management, we now contract the delivery of our seedlings to the various drop points across the state rather than doing it ourselves. We now contract the stratification of our pine and poplar seed. We contract the lifting and packaging of our seedlings. We have gone from 15 full time and 20 seasonal to 5 full time and 2 seasonal employees. Our annual revenue has risen from $450,000 to $966,000. We are building a greenhouse to start producing some containerized seedlings. We no longer use a belt lifter to lift our seedlings. We now accept credit cards as payment. Thirty-five acres of seedling production have been added. We have joined the NC State Loblolly Tree Improvement Cooperative. We have hired a second tree improvement specialist.

The landowners in Tennessee are becoming better stewards of the land. This new ethic has made a tremendous difference in not only increased tree planting but in all aspects of forest management.

QUANTITY-BASED VERSUS QUALITY-BASED PRICING: DEVELOPING THE NICHE PINE SEEDLING

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Abstract

Demands placed on pine production in the southeastern part of the United States prompt managers to research and employ intensive cultural practices. Bareroot conifer seedling culture, like loblolly pine (*Pinus taeda* L.), is highly preferred in moderate regions of the South, since bareroot stock is relatively inexpensive to purchase, transporting and planting costs are reasonable, and field survival and growth measures are tolerable. For almost 50 years, Philip Wakeley's *Monograph No. 18* has been used as the "bible" for the cultivation of southern pines, because sound prescriptions have served many nurseries well. In recent years, some of the methods commonly employed have been challenged in different ways, like that of decreasing seedbed density. To lower seedbed density has been shown to increase seedling root collar diameter, and thus improve seedling survival and growth potential. Some conditions that result from using this method to produce new archetypical, "high-quality" seedlings will involve the elimination of stems from a nursery's productive capacity (for example, reducing sowing densities from 330 to 110 seedlings/m^2). Cost efficiency evaluation can be employed by a nursery to analyze this and other production operations for any species. If cost information were openly shared among firms, benchmarks would indicate a nursery's position among other nurseries. Since cost information unique to a nursery's operation is confidential, and cash flows are considered proprietary, it seems more proper to use publicly disclosed information, like values of seedling price and yield (in other words, diameter and height), when comparing firms. Price efficiency evaluation is an acceptable model, since actual expenditures can remain conspicuous. If pricing standards were designed according to a "quality-based" format instead of the current "quantity-based" format, then perhaps the lowering of seedbed density to produce high-quality seedlings could be justified. It is quite costly to take seedlings out of production, and so it is essential to increase prices for "niche" products. Some firms (public and private) are beginning to employ niche-pricing strategies. If quality-based pricing schemes were adopted, nursery managers would be motivated to find other ways to produce valuable niche products, without reducing seedbed density. There are other low-cost cultural measures that, if incorporated into current operations, would serve to increase production efficiency.

Key Words

Niche products, efficiency, quantity-based and quality-based pricing, seedbed density, *Pinus taeda*

AN ECONOMICAL/ECOLOGICAL PARADOX

Whatever befalls the earth befalls the sons of the earth. Man did not weave the web of life; he is merely a strand in it. Whatever he does to the web he does to himself
—Attributed to Chief Seattle 1854

With 25% of the world's population consuming about 80% of the timber, paper, and energy (Durning 1992), a large "ecological footprint" (Rees 1996) has been stamped on this generation (Lemons 2000). Most of us recognize that this situation demands immediate attention, and few would argue against restoring ecosystems to their

pristine conditions (Hull and Gobster 2000). But the daunting task of how to regenerate our forests rests somewhere between natural and artificial means (Schultz 1997). While ecological and economical principles may seem separate, they are actually connected like strands in a web (Chief Seattle 1854). To illustrate this interaction on a national level, C. W. Lantz (1996) has pointed out that as logging becomes restricted in the West, the South is called upon to supply a nation's timber needs; unfortunately, planted acres have continued to decline and lag behind harvested acres, from 60% in 1989 to about 40% in 1996. This regeneration paradox is not only domestic but also international in scope, since our world is both economically and ecologically bound.

A partial solution to this regeneration dilemma may ultimately be found at its core level—the forest nursery. Whether public or private, forest nurseries try to balance seedling quantity (for cost reduction) with stem quality (for plantation success). In the South, loblolly pine (*Pinus taeda* L.) is a highly preferred and culturally propagated forest species (Schultz 1997), but in general this quantity-quality relationship can be applied to all species. Quality standards have been proposed and are currently utilized in nursery practice with the intent of producing the ideal seedling (Mexal and South 1991), but evaluating the additional costs involved in developing this seedling, and determining a fair-market value for its purchase has been elusive. The niche pine seedling is just another term used to describe what is targeted as an optimal quantity-quality compromise. Pricing this niche product, and promoting its development is the focus of this paper. To realize the value of the optimum is to recognize the value of common stock, and long-term value will be attributed to successful forest establishment. While nurserymen and landowners have commonly expressed their concerns, the planter's viewpoint should be no less important, because unless affordable stems are made suitable for planting, nursery gains may be lost in the field.

Tree Planter's Perspective

The planting of trees is the least self-centered of all that we do. It is a purer act of faith than the procreation of children —Thornton Wilder 1967

The southern forest industry has evolved tremendously over the last two decades (Lantz 1996), and so planting companies in the Southeast are pressured to keep pace with industrial demands. My initial perspective of forestry in the U.S. has been structured around supplying this demand for large-scale reforestation. From Texas to Florida (seasonally from 1982 to 1988), I typically planted conifers at rates from 3,000 to 6,000 stems per day, depending on factors like soil type and site preparation. Equipped with a hoedad (a mattock-like tool) and a planting bag (to carry hundreds of seedlings), the hand planter (paid on a piecework basis) is well motivated to perform high-volume planting. Quality control standards were often imposed by continually inspecting procedures of seedling handling and planting, but seedling size standards were not commonly emphasized. Bareroot loblolly pine seedlings (sizes averaging about 4mm in diameter) were commonly planted, and planting was greatly facilitated under workable conditions involving sandy soils and level terrains. In the Pacific Northwest (1984 and 1985), steep terrains, rocky soils, and variable weather conditions at high elevations were experienced. Most of my time was spent planting in Montana and Idaho, and containerized conifers with variable stem sizes were commonly supplied.

During the planting off-season in the United States, I visited 22 countries in Europe and demonstrated American tree planting tools and techniques for as many as were interested. As an entrepreneur, I would locate the office of forestry (or the like) in whatever city I was in at the time. Once located, I offered them a demonstration of the hoedad and tree-planting bag, promising to plant at a rate of 2,000 stems in 6 hours. Once accepting the piecework rate of pay (not typical in some countries), the demonstration was conducted for a limited time, involving from several hours to several weeks to accomplish. Since I had no prior knowledge of seedling standards for a particular region before my arrival, the guarantee of 2,000 stems in 6 hours was sometimes quite difficult to honor. In one instance (for example, Belgium), my brother (who attended me for a few months) and I discovered that some seedlings were not suitable for large-scale reforestation; one sapling was a handful, instead of a handful of seedlings. In Turkey, forty seedlings were easily held in one hand, fitting the high-volume reforestation prototype. From country to country, and region to region, seedling

standards varied considerably even for the same species in similar environmental conditions. As these experiences suggest, seedling standards are not only needed throughout the U.S, but throughout Europe as well, fostering the production of quality (niche) products.

Forest nurseries (whether domestic or international), and many groups involved in reforestation, frequently pursue the optimum (niche) seedling, but few offer tenable solutions. Because of growing consumer demand, nursery managers are continually pressed to produce more goods of higher quality with fewer resources in less time. If this were not enough, managers are also asked to certify plantation success in terms of stem survival and growth. There are measures that, if taken, ensure the production of high-quality stems, but these result in reduced quantities because of lower seedbed densities. The quantity/quality conflict arises when nurseries attempt to balance high-quantity demands with high-quality standards. Although solutions may be proposed to address these quantity and quality issues alone, quantity-driven cost and quality-driven yield factors must be addressed in an integrated form at the same time period. Truly, the magnitude of this cost/yield (quantity/quality) relationship needs more clarification. Utilizing the treatment scenarios in a study installed in 1999, the cost/yield impacts of some common southern forest nursery practices were contrasted with some uncommon (or unusual) practices, and should thereby serve to illustrate some of the dynamics involved in the development of the niche pine seedling.

Treatments of the 1999 Nursery Study; Developing the Niche Pine Seedling

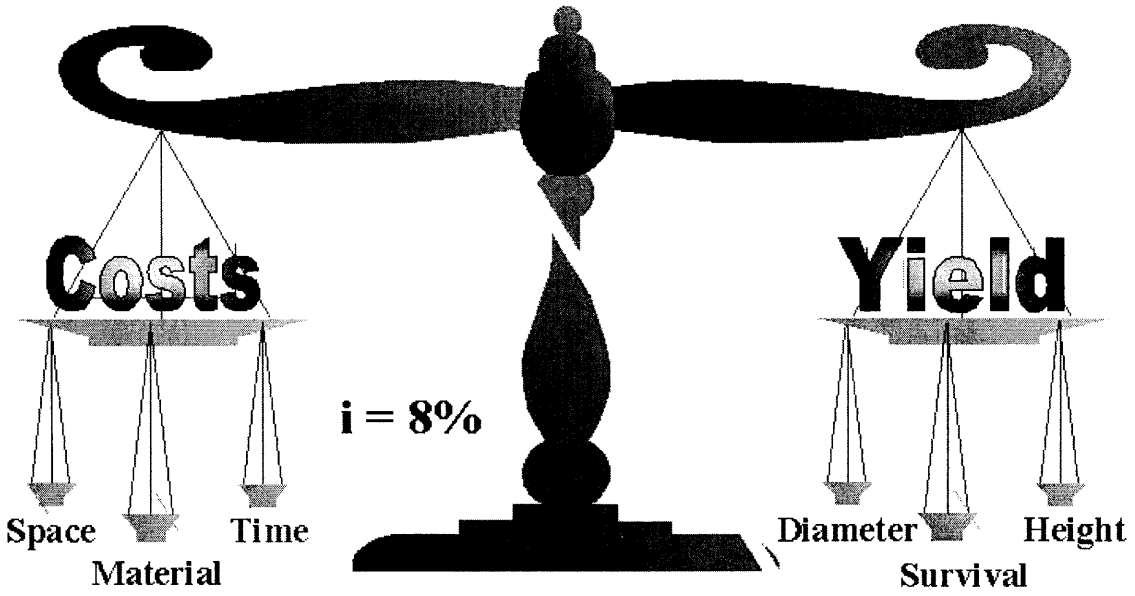
Art imitates Nature, and necessity is the mother of invention —Richard Franck 1658

If necessity is the mother of invention, then resourcefulness is the father —Beulah Louise Henry 1962

The four treatment factors employed in the 1999 nursery study for the culture of loblolly pine were: 1) seedbed density spacing (110, 330, and 550 seedlings/m^2; divide by 11 to convert to ft^2); 2) sowing mechanisms of symmetrical versus precision sowing; 3) fertilization regimes (organic, inorganic, and their mixture); and 4) tops trimmed versus tops left intact. Without going into great detail, these 36 treatment combinations represent an array of strategies that may or may not be suitable for southern pine production. For example, precision sowing at 330 seedlings/m^2, inorganically fertilized with tops trimmed is a commonly employed combination, but symmetrical sowing at 550 seedlings/m^2, fertilized with manures alone, and tops left intact is virtually nonexistent. All treatment combinations were randomly positioned, which includes 2 blocks having 3 replications per treatment combination.

Any cultural system, whether currently utilized or under consideration in nursery practice, can be priced from either empirical data or hypothetical estimation. Balancing these costs (the inputs involved in production) with stem yield (the output of production) can be a useful tool to illustrate cost/yield integration (Figure 1). The three basic elements of cost estimation include that which is involved in: 1) the acquisition of material; 2) the occupation of space; and 3) the employment of time. In our study, these dollar values were combined and compounded at 8% interest for each treatment combination. The three basic elements used to estimate yield include: 1) ground-line diameter combined with 2) stem height (offering a measure of individual stem parabolic volume); and 3) percent survival (adjusting yield estimation at both nursery and plantation levels). Once both sides of the equation have been developed, the cost-yield integration (in other words, cost efficiency ($/$dm^3$)) can be effectively used to evaluate any given treatment combination, and to select the optimal (niche) treatment or operation. This paper offers a summary of the results uncovered in the 1999 loblolly pine study. A more comprehensive discussion of the findings contained herein is yet to be published (Howell 2001).

Of all the cultural treatments observed in this study, seedbed density (Figure 2a) offers the greatest impact on stem diameter for all southern pines (Boyer and South 1987). The 3 densities in our study evaluated a commonly utilized density (330 seedlings/m^2), an upper extreme density (550/m^2), and a lower extreme density (110/m^2). It only stands to reason that crowded seedlings



$$C_t = C_{sum} * (1+i)^t \qquad E_t = C_t / Y_t \qquad Y_t = (\Pi * r_t^2 * h_t)/2 * S_t$$

($) ($/dm^3) (dm^3)

Figure 1. The cost-yield scale illustrates the balance between the factors of costs (material, space, and time) with the factors of yield (survival, and diameter and height growth). The cost (C_t) equation sums up all relevant values ($) pertinent to a particular operation, and compounds C_{sum} forward to a specified time (t) at a given interest rate (i) which was 8% in our study. To discount future costs back in time simply divide instead of multiply. The yield (Y_t) equation averages the parabolic estimate of stem volume, which is determined by ground-line stem diameter (radius (r) at time t squared), multiplied by stem height (h) at time t, multiplied by Π (3.14159), and divided by 2. Since the yield value is expressed in cubic decimeters (dm^3 which equals one liter), all components must be converted to like dm units. Survival (%/100) adjusts for mortality the volume estimate when a nursery or plantation-level expression is required. Cost efficiency (E) at time t expresses the integration of costs and yield ($/dm^3).

promote upward growth as opposed to outward growth. This outward diameter growth, root collar diameter (RCD), has long-time been recognized as a good indicator of stem quality (Mexal and South 1991), and the archetypical (niche) seedling should have a large RCD. Exactly how large a RCD must be is yet to be defined; nevertheless, high quality stems are likely to have good root growth potential (RGP), and good RGP promotes long-term plantation success (Larsen and Boyer 1986; Schultz 1997). Over time and across regions, specifications are subject to change, depending on customer demand for RCD standards; and the nursery's ability to meet customer demands at the price the customer will afford. The cost-benefit balance pivots on what size a RCD should be in order to ensure good field survival and stem growth; and how much it costs to obtain the specified RCD. In the field it has been observed that crowding is regulated by the "self thinning" –3/2 power rule, which states that as individual stem diameters increase, stem numbers will proportionally decrease (Weller 1987). The results from our study support this rule, since the largest stems were found at the lowest seedbed density. To the frustration of many nursery managers, it is not cost justified to concede quantity (in other words, reduce seedbed density) in order to satisfy requests for higher quality (Foster 1956; Shoulders 1961); therefore, what should give?

If symmetrical sowing were utilized more in practice, nurseries might find a tool to effect high yields at high densities (Figure 2b). Mechanical, precision sowing is standard practice for sowing southern pines in the southeast, and specifications

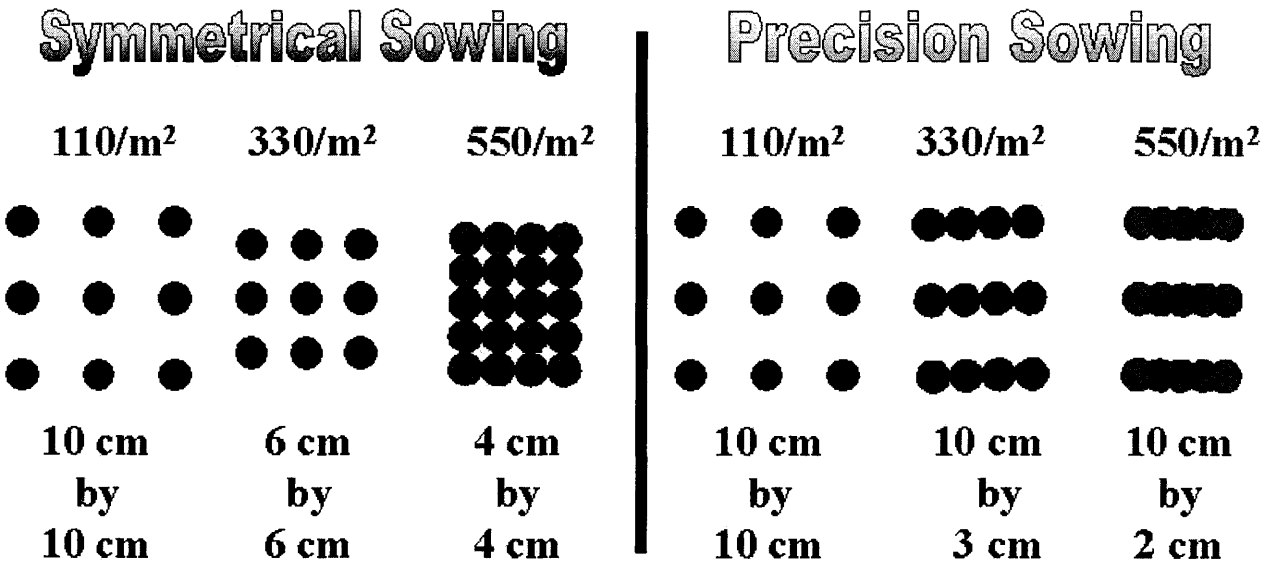


Figure 2. Seedbed densities are displayed from the very low (110 seedlings/m^2) to the moderate (330 seedlings/m^2) to the very high (550 seedlings/m^2) in order to illustrate the dynamics of initial spacing and the potential for crowding with seedling growth. Symmetrical versus precision sowing illustrates the trade-off that the 4-inch (10-cm) between-row spacing has on within-row spacing as density increases as compared to the lowest density.

retain 4 inches between rows for purposes of 1) lateral root pruning and 2) seedling lifting. Lateral root pruning trims only two of the four sides along the seedling's root system, and in some years the procedure is avoided. Lateral root pruning was not performed in our study, and field survival is so far unaffected, which implies that the procedure may not be cost justified. As for lifting, specially designed forks, extending before the lifting belts, effectively channel seedlings into the belts, regardless of tight spacing (Figure 3). In fact, seedlings were cleanly lifted from densities over 1,100 stems/m^2 (100/ft^2), which were broadcast sown. Since mechanized symmetrical sowing is not yet operational, we utilized the Hand-sowing Press™ for the preparation of seed sowing (Figure 4). Results indicate that nurseries symmetrically sowing can produce larger stems at current densities, or average stem sizes at higher densities. If utilized with other methods, large stems may be produced at high densities. It should be pointed out that precision sowing at the lowest density had a spacing configuration that was basically equivalent to that of symmetrical sowing. The main finding from this test revealed that maintaining a 4-inch spacing between rows is not cost justifiable at high densities, because spacing within the row must be restricted. However, to further validate these findings, a test involving mechanized symmetrical sowing on a large scale is recommended.

To maintain a soil's fertility and a site's productive potential for a particular species, nursery managers are obliged to find that delicate balance among the choices of: 1) what fertilizer to use; 2) how much to use; 3) when to use it; and 4) how to apply it (May and others 1984). Because there is the potential of declining soil productivity in heavily used nursery soils, it is essential to continuously test new nutritional enhancement (fertilization) strategies with those existing procedures. In our study we tested the effects of a relatively inexpensive organic fertilizer alone, in the form of municipal waste (biosolids), inorganic fertilizer, which is routinely utilized in nurseries, and a mixture of organic and inorganic fertilizers together. The high macro and micronutrient availability was a positive contribution that supported the use of the organic source, but the plant available nitrogen (PAN) aspect of the material was lacking. Organic manures may be



Figure 3. Forks that extend in front of the belts on the lifter, channeling seedlings into the belts (left). The lifting operation was successfully performed (right) with stocked seedbed densities greater than 1,100 stems/m^2.

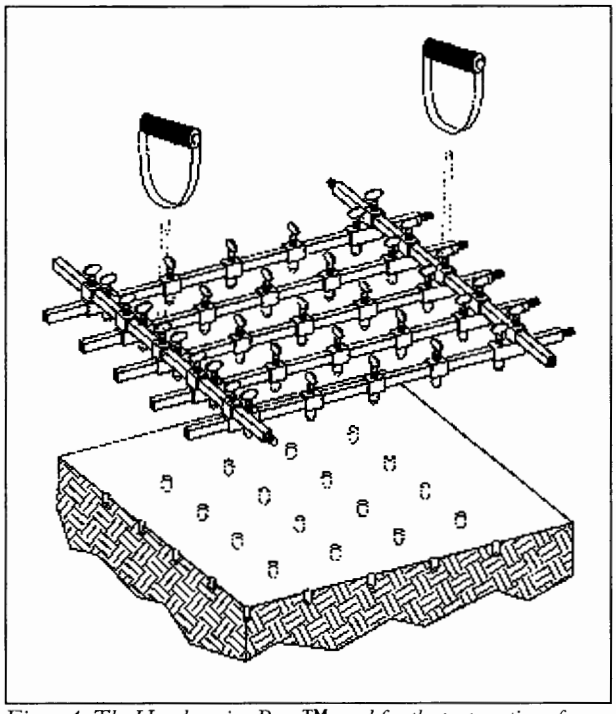


Figure 4. The Hand-sowing Press™ used for the preparation of seed-sowing impressions specifically for the symmetrically sown treatment.

used to supplement those nutrients typically neglected, because inorganic fertilizers are too costly, or because other sources are unavailability. The most conclusive findings of this test were to substantiate the proposition that nutritional enhancements can promote greater yield at higher densities (Schultz 1997). Fertilization is highly justifiable, because its monetary investment is far lower than some of the more conventional measures currently encouraged to promote stem yield (for example, lowering seedbed density).

The fourth treatment we looked at in our study was that which involved pruning only the succulent tops of loblolly pine versus not trimming the tops (Figure 5). More than 90% of all southern forest nurseries top prune (Duryea 1987). Some nurseries top prune to control height and slow down diameter growth at critical times (Schultz 1997), while others prune to increase the root-to-shoot ratio and improve uniformity among stems (Mexal and South 1991). Uniformity was the feature that supported top pruning in our study, since opening up the canopy permitted suppressed stems to get sunlight, and the size of dominant stems (those first to germinate) was partially reduced, and growth was temporarily slowed. Fewer culls result from this procedure, and seedlings are easier to pack and store (Davey 1982). As long as top pruning is not performed too late in the growing season or too low on the stem, the benefits of the procedure far outweigh the negligible costs involved in passing over the crop with a rotary mower.

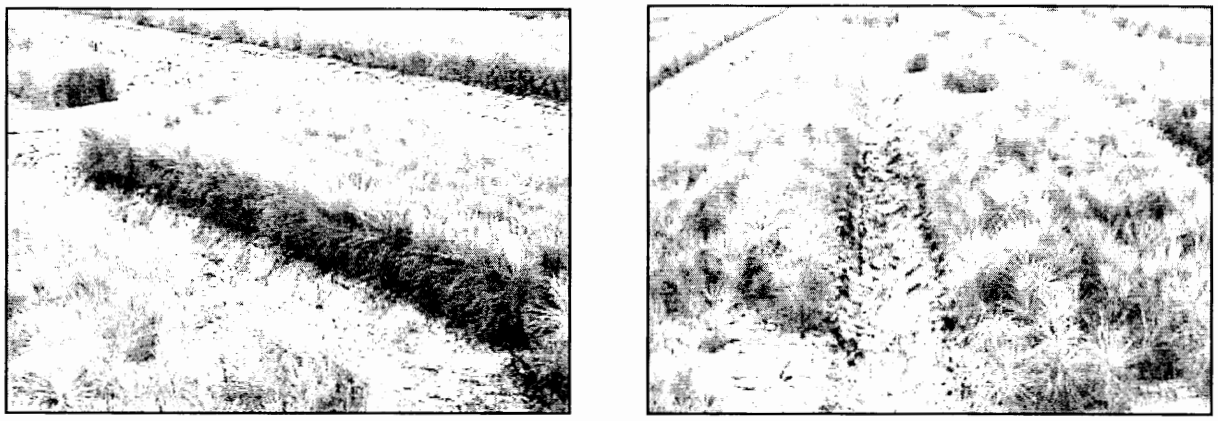


Figure 5. Top pruning (9-7-99) of succulent tops (left) versus tops left intact (right). The pictures were taken on November 11, 1999.

Cost Versus Price Efficiency: Assessing Current Operations

To expect to increase prices and then to maintain them at a higher level by means of a plan which must of necessity increase production while decreasing consumption is to fly in the face of an economic law as well established as any law of nature —Calvin Coolidge 1927

That which is considered to be an ideal seedling depends on whether nursery practices are quantity based or quality based. When a nursery is designed for quantity-based production, high seedbed densities are preferable so that large numbers of seedlings can be produced, and therefore a relatively small RCD will be acceptable. On the other hand, a quality-based nursery operation will restrict seedling numbers in order to obtain recommended RCD specifications having larger than normal caliper sizes. Currently, grading standards for loblolly pine (as with other southern pines) are widely recognized (Figure 6), where stems with RCD sizes greater than 5mm are considered high quality stems (Grade 1). Typical RCD size standards range from between 4 and 5mm (Grade 2), and those RCD sizes below 4mm may be considered culls in some nurseries (Grade 3). It is important to note that grading standards of quality are subject to adjustment with region and with time. Thus, a Grade 1 seedling today in one state may be considered a Grade 2 seedling in another state today, or in the same state tomorrow.

Changing standards can promote technological progress, but currently prices are not designed to adapt with changing standards. The paradigm of pricing solely on a quantity-based ($/1000) system should incorporate quality-based measures ($/1000 according to RCD) in order to advance innovative technology, and to reward those firms that perform it. To illustrate this, consider a comparison of grades (Table 1) that are based on those average RCD sizes of Figure 6. Yield, expressed in $dm^3/1000$ (liters/1000), gives more weight to RCD in the volume equation than to height (held constant at 25 cm), and parabolic volume is sufficient to be a conventional measure of size. As found in the 1999 nursery study, the densities of 110, 330, and 550 seedlings/m^2 were shown to produce seedlings with respective average RCD sizes of 5.5, 4.5, and 3.5mm, and thus are assigned the grades of 1, 2, and 3, respectively. For illustrative purposes, suppose by the implementation of an innovative practice, like mechanized symmetrical sowing, grades 1, 2, and 3 were produced from respective densities of 220, 440, and 660 seedlings/m^2. And by further innovation, like fertilization, the same grades may be produced from respective densities of 270, 490, and 710 seedlings/m^2. What is the limit to innovation? Is it likely that by some innovative technology or tool the same grades could be produced from respective densities of 330, 550, and 770 seedlings/m^2? In this technological age, it is not only possible, but it is highly probable that these higher grades will be produced at higher seedbed densities.

As densities decrease, there is an associated increase in cost (Table 1) that must result when decreasing the number of seedlings offered to the market place. The sale price will reflect a firm's permission to markup (in other words, make profit or cover hidden costs) with respect to the market's cap on pricing. An acceptable price floor

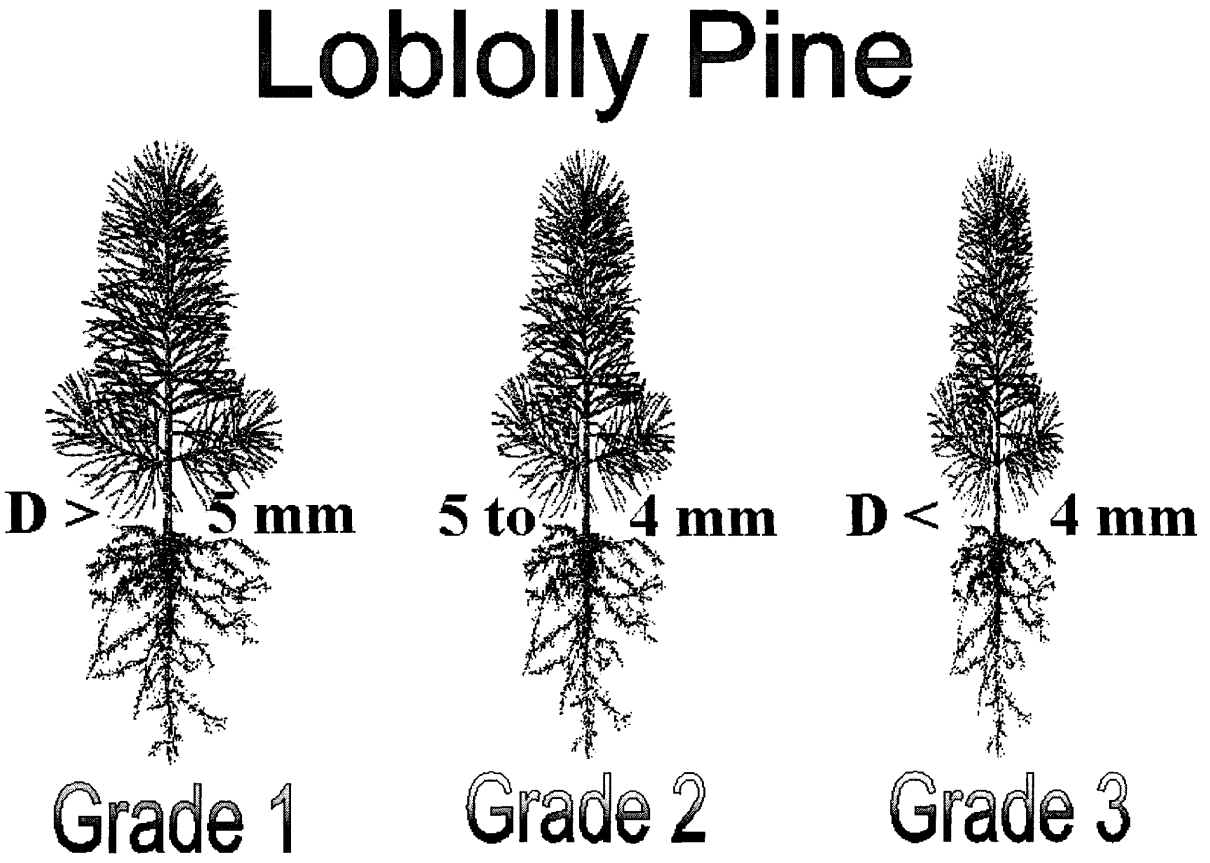


Figure 6. Three grades of seedling quality for loblolly pine based on root collar diameter (RCD) greater than 5mm (Grade 1), RCD between 5 and 4mm (Grade 2), and RCD less than 4mm (Grade 3).

Table 1. Comparing aspects of seedling size resulting from cultural practice. Grades are based on root collar diameter (RCD) in millimeters. Other factors illustrated are height (cm), and yield dm^3/1000. The comment column clarifies the row's function. The common density (Common: (stems/m^2)) shows common densities required to produce specific grades. The costs incurred to produce stems at common densities (ComCost ($/1000)) utilizing typical cultural practices are shown with respect to the common price (ComPrice ($/1000)) required to cover all costs (obvious and hidden) depending on a firm's convention to markup the price. Cultural practices can serve to produce larger RCD at similar densities as compared to that of common practice. Hypothetical examples of culture in additive fashion are: mechanized symmetrical sowing (MechSym: (stems/m^2)), soil additives, fertilization, hormones, and so on (Additive: (stems/m^2)), and other systems of innovative technology (InnoTech: (stems/m^2)).

	Grades According To Seedling Size			
	Grade 1	**Grade 2**	**Grade 3**	**Comments**
RCD (mm)	5.5	4.5	3.5	Average RCD provides the basis for grading
Height (cm)	25	25	25	Height is commonly controlled by top pruning
Yield (dm^3/1000)	3.0	2.0	1.2	Volume of liters/1000 is equivalent to dm^3
Common: (stems/m^2)	110	330	550	Common density produces the applicable grade
ComCost ($/1000)	77	31	22	Common production cost is a function of density
ComPrice ($/1000)	??	??	??	Common price depends on "all" costs & markup
SymSow: (stems/m^2)	220	440	660	Potential shift from symmetrical sowing
Additive: (stems/m^2)	270	490	710	Potential shift from additive, fertilization, and so on
InnoTech: (stems/m^2)	330	550	770	Potential shift from other technological systems

or ceiling must reflect the quality of the stock made available, which requires that new standards of seedling quality be promoted, and assumes that consumers will pay more for better products. There are some nurseries (for example, Private Firm #1) that lead the way in this endeavor (Table 2). Private Firm #1 claims it has Grade 1 seedlings with RCD sizes from 5.5 to 6.5mm, and its Grade 2 seedlings have RCD sizes from 4.5 to 5.5mm. One must assume that Grade 3 stems (less than 4mm) are not acceptable for the market with this firm. According to their 2001 price list, both grades are priced at $75 and $48/1000 for Grade 1 and Grade 2 seedlings, respectively. With respect to the sizes expected from seedlings grown in low densities (110/m2), the cost should be as high as $77/1000 (Table 1), but Private firm #1 has a price of $75/1000. Although this firm claims (while not offering specifics) that these seedlings were produced at a lower seedbed density than is typical, their price suggests that density has not been radically reduced. Even their Grade 2 stems are of better quality than the best some firms have to offer. How do they do it? Without knowing the specifics, supposition is necessary. Therefore, I suppose that they use in combination some cultural treatments like those mentioned above, and apply them on densities slightly lower than normal. More importantly, it is preferable to pay workers to separate stems into several grades, because grade prices significantly outweigh separation costs.

The dynamics of cost and price efficiency as comparative measures (Table 3) are illustrated among the following nurseries: Private Firm #1, Private Firm #2, and a Public Firm. For the sake of illustration, average RCD sizes are stated and grades are implied in yield (dm^3/1000). Accordingly, Private Firm #1 is the only nursery offering substantially Grade 1 seedlings ($75/1000), and the other examples offer Grade 2 seedlings (in other words, RCD = 5mm and Yield = 2.5 dm^3/1000). Private Firm #2 charges $50/1000 for Grade 2 stems, while Private Firm #1 charges $48/1000, and the Public Firm charges $41/1000. Which price is fair? On the surface, based on what is known (price and yield), the public firm offers the best price efficiency at $16/$dm^3$. However, while price efficiency shows the consumer's gain, it hides the nursery's real situation, which only cost efficiency can show. If there were no proprietary costs (in other words, nothing secret), then one could look at cost efficiency across all firms, and in this case the real

Table 2. An illustration of how Private Firm #1 is leading the way in the promotion and pricing of loblolly pine seedlings based on RCD grading. As provided by firm #1, Grade 1 (6.5 to 5.5 mm) and Grade 2 (5.5 to 4.5mm) seedlings are made available to the market, but Grade 3 (less than 4.5mm) seedlings are apparently culled. Prices ($/1000) are also provided from firm #1effective for the 2001 growing season, but costs are not provided due to proprietary concerns.

Pricing Scheme For Private Firm #1				
	Grade 1		Grade 2	Comments
RCD (mm)	6.5	5.5	4.5	Grade 1 = 6.5 to 5.5 & Grade 2 = 5.5 to 4.5
Height (cm)	25	25	25	Height is commonly controlled by top pruning
Yield (dm^3/1000)	4.0	3.0	2.0	Volumes in effect increase with respect to RCD
Price ($/1000)	75		48	Prices as quoted from firm #1 for 2001.
Costs ($/1000)	??		??	Costs are unknown due to proprietary concerns

Table 3. A comparison of firms using price efficiency and cost efficiency values. There are two private nurseries (private #1 and private #2) and one public nursery in this comparison. Prices are effective for the 2001 growing season, and costs are hypothetical for illustrative purposes. Lowest values are in bold text.

Comparing Price and Cost Efficiency Among Firms					
	Private #1		Public	Private #2	Comments
RCD (mm)	6.0	5.0	5.0	5.0	Average RCD are shown for each firm
Yield (dm^3/1000)	3.5	2.5	2.5	2.5	Volumes increase with respect to RCD
Price ($/1000)	75	48	41	50	Prices quoted from Firms' 2001 price list
Price Efficiency	22	19	**16**	20	Divide price by yield to calculate values
Costs ($/1000) ??	42	30	35	30	Hypothetical cost values for each firm
Cost Efficiency ??	**10**	**10**	14	14	Divide cost by yield to calculate values

winner with the most efficient operation would be Private Firm #1, with respect to both of its grades at $\$10/dm^3$.

Since prices are adjustable, and "all" costs must be recovered in price, it is important that the difference between identified costs and the asking price be accurately estimated. Regrettably, unforeseen costs in a competitive environment complicate pricing schemes, leading to product devaluation. Comparing hypothetical profit margin scenarios among the firms in Table 4 should better illustrate this situation. The first scenario accounts for the Public Firm (assuming a 20% markup) having the lowest price efficiency value (Table 3), but sharing an equally high cost efficiency value with Private Firm #2. Intuitively, those firms with higher prices, with respect to their published costs, enjoy higher profit margins (for example, the exorbitant 80% of Private Firm #1). Even if this hypothetical gain were real for Private Firm #1, to avoid being accused of price gouging or profiteering, the firm could create new costs (for example, investments, salaries, and so on) and could report lower profits than would otherwise be revealed. Investments are justified to promote innovation, because when innovation transforms an operation, lower production costs can result in higher gains. As scenario 2 (Table 4) illustrates, the Public Firm develops an innovative system, and due to its fixed hypothetical gain of 20%, all cost savings are seen in the lower price to the customer. Moreover, if this Public Firm were to be even more industrious (scenario 3), adopting better systems to further lower costs (assuming unchanged product quality), the price might be lowered further to $\$25/1000$. Suddenly, the Public Firm's innovation has introduced a pricing dilemma to the market place, and many established paradigms become challenged.

Change can be good, but most businesses need time to modify existing operations, to adjust current prices, and to stay competitive. Upgrades are expected from private firms, because they are market-driven entities. However, what are the consequences of public firms developing new and innovative systems? A publicly owned firm currently has several alternatives, it can: 1) refuse to employ any innovative system until it has been developed by the private sector and becomes

Table 4. A comparison of hypothetical profit margins (gains) among nurseries. The first profit margin scenario (PM Scenario 1) depicts how existing increases might look. Changes of interest are in bold text. The second scenario (PM Scenario 2) depicts how an innovation can save money (Costs 2) and the savings are passed on to the consumer (Price 2), since the profit margin is fixed. Open quotes (") indicate that values are same as above. The third scenario (PM Scenario 3) depicts how increased innovation can continue to lower costs, which means more savings to the consumer, as long as the profit margin remains fixed. The fourth scenario (PM Scenario 4) depicts a situation of continued low costs, and increased profit margins respectively at 30% and 40%. This scenario rewards the firm for implementing innovation, while continuing to offer low prices to the customer.

	Profit Margins Observed Among Firms				
	Private #1		Public	Private #2	Comments
RCD (mm)	6.0	5.0	5.0	5.0	Average RCD are shown for each firm
Yield (dm^3/1000)	3.5	2.5	2.5	2.5	Volumes increase with respect to RCD
Price ($/1000) 1	75	48	41	50	Prices quoted from Firms' 2001 price list
PM Scenario 1	**0.8**	**0.6**	**0.2**	**0.7**	**How existing margins might look if known**
Costs ($/1000) 1	42	30	35	30	Hypothetical cost values for each firm
Price ($/1000) 2	"	"	**35**	"	**Savings are passed on to the consumer**
PM Scenario 2	"	"	**0.2**	"	**Profit margin held at predefined rate**
Costs ($/1000) 2	"	"	**30**	"	**After some innovation lowers cost**
Price ($/1000) 3	75	48	**30**	50	**More savings for the consumer**
PM Scenario 3	0.8	0.6	**0.2**	0.7	**Profit margin held at predefined rate**
Costs ($/1000) 3	42	30	**25**	30	**More innovation can lower costs further**
Price ($/1000) 4	"	"	**33** **35**	"	**Customer saves & the firm is rewarded**
PM Scenario 4	"	"	**0.3** **0.4**	"	**Profit margin shown at two higher rates**
Costs ($/1000) 4	"	"	**25** **25**	"	**Cost savings held at the low value**

public domain; 2) employ innovations at will and continue to lower prices since restrictions currently forbid profit making; or 3) employ innovations and slightly increase the percentage retained in profit to offset declining prices (PM Scenario 4 in Table 4). This is the "niche" pricing alternative. With this pricing alternative the firm must add a "profit margin," but many public firms are only permitted to cover costs, and find it difficult to justify even the most essential increases in price. However, there are those who feel that this paradigm restricts sound business practice for publicly owned entities (Alchian 1965; Hayes and Pisano 1994). Nevertheless, when profits are increased slightly, declining costs are offset with the adjusted price, the firm (public or private) is then financially rewarded with increased revenue, and is also encouraged to employ efficient systems in the future. Niche pricing ensures that the quantity of a product purchased has the quality expected! Niche pricing puts a check (in other words, a price ceiling) on prices to prevent firms from exploiting the market with exorbitant prices. Furthermore, niche pricing can impose a price floor, permitting competing firms sufficient time to upgrade operations and adjust prices.

Pricing Niche Products: Rewarding Individuals, Businesses, and Society

There is nothing man will not attempt when great enterprises hold out the promise of great rewards —Titus Livius (Livy) 59 BC

A satisfied individual (employee or customer) offers the greatest potential to reward a business (an organization of individuals). At the most basic level, the success or failure of a business hinges on how individuals are treated. In fact, creating worker incentive may be the best innovative measure to ensure a firm's success. Rather than resorting to the stick approach (continuously threatening employees with job security), incentive measures utilize the carrot approach, which treat all employees like fellow partners in the business. It is the spirit of teamwork that instills pride in accomplishing the task at hand and doing the best job possible (Alchain and Woodward 1987), as opposed to being an unappreciated worker who feels dissatisfied, and whose "chores" are reluctantly performed. While a business may stress high output volumes through quantity-based incentive measures, to neglect quality-based incentives will eventually damage a firm's reputation inside and out. If quantity-based and quality-based measures were engaged in a complimentary fashion, a firm might vertically integrate an operation, instead of resorting to contracts, which may cheapen the product's quality, and also damage the firm's reputation (Hayes and Pisano 1994). By educational measures of instruction, and with task-based incentive plans, satisfied employees will be determined to produce niche products, respectable to the customer; on the other hand, the exploited, abased employee within the insensitive firm may deliver many suspect goods to the market. All the innovation in the world cannot replace the innovation that supports the individual, and why spend millions of dollars for innovations, while the operators are not motivated to operate them effectively? Reward conveys autonomy, stimulates positive action, encourages inventiveness, and permits a person to invest in the firm, and to feel responsible for company success.

A healthy business (a conglomeration of satisfied individuals) has great potential to reward society as a whole. Business health can be compared to a body of members working in unison to accomplish a given task, in our case to produce the niche seedling. Whether a business is publicly or privately owned, if it develops or cultivates similar products as other firms in the market, it may also be subject to most of the expenses experienced by other firms. Businesses hire from the same human resource pool and must offer competitive salaries, they suffer the same costs for resources (land, buildings, chemicals, equipment, and so on), they often strive for customers and must meet customer demands, and the list goes on. With respect to these similar constraints, the public firm's accounting methods are often distinguished from those of the private sector, because those unexpected, hidden costs can be conveniently covered with a profit margin by the private firm. Although "both public and private property can seek profit" (Alchian 1965), most publicly owned properties are not permitted to announce any intent toward the creation of wealth or the maximization of utility. In today's precarious market place this can cause a tremendous strain on any firm with genuine business concerns (for example, predicting future trends, meeting customer demands, and staying current in technology). With respect to the current paradigms that have predestined a firm's function

in a particular field, there are competitive elements that tend to level the playing field with no respect to organization. Regardless of whether a firm is publicly or privately owned, to survive is to grow, and growth is contingent upon obtaining appropriate provisions. You will not grow if you are not permitted to eat! While most publicly owned firms are not permitted to be dominant among other firms, co-dominance may be suitable, to be intermediate may be tolerable, but to be suppressed among firms for an extended period of time will eventually compromise a firm's integrity.

When satisfied individuals work together in a company to produce high-quality (niche) products, and when these products are accurately valued, society wins. Never in earth's history has it been as important as it is today to produce more products of higher quality in less time, and with fewer resources. To practice regeneration efficiency is to seek that quantity/quality, economical/ecological balance. If it were easy, then society would have stabilized these systems long ago, but reality testifies that our forests are declining faster than they are regenerated (Lantz 1996). Since present harvesting mechanisms have become state-of-the-art, businesses involved in reforestation must do more than keep pace, but they must exceed harvesting rates. Our focus in this paper was on the forest nursery, suggesting several key innovations in production, but plantation forestry should also be challenged to advance the niche product in the field and throughout its life span, producing higher volumes on less land, sooner. In other words, when planted stems are larger than normal, stands start out morphologically older, rotation lengths are chronologically shorter, and initial costs are not carried so far into the future. Moreover, this forestry-horticultural compromise will give some species that essential head start required to promote multiple-species plantations. Besides encouraging multicultural endeavors, lateral branch pruning, fertilization, and other cultural practices in the field may also facilitate stem growth sooner, at higher densities, and with greater stem and stand volumes. Since our wild lands are threatened on every side (urbanization, agriculture, forestry, husbandry, catastrophic events, and so on), better management practices on those lands that have already been manipulated should be encouraged to supply a nation's timber needs. Therefore, when the needs of the timber industry have been satisfied with fewer lands, then many of the regenerated areas may rest in peace, and most of our pristine wilderness areas that still remain will be preserved as an ecological reward to society.

As the dynamics of an economical/ecological forest regeneration paradox unfolds, the consequences will surely be felt universally, and so resolutions should be sought everywhere and by everyone. Niche pricing is designed to encourage the development of niche products, which in turn "reward" those involved in the process (in other words, individuals, businesses, and most importantly society). To base rewards on achievements is not a new practice, as Titus Livius reminds us, but the best way to reward appropriately is questionable. Whether compensation is economical or ecological, monetary or aesthetic, physical or psychological, the one compliments the other like an interwoven web (Chief Seattle1854), and the recipient will decide if it has been satisfactorily implemented. If this natural bond were fully appreciated, every enterprise receiving monetary gain from the forest would gladly return financial aid to guarantee fast and sufficient restoration of all natural ecosystems. Although benefits may be hard to assess monetarily (Montgomery and Pollack 1996), payments must become tangible to all beneficiaries. Then in the course of time, by and by, our rejuvenated natural resources will continue to support incredible wealth, and will continue to create unbounded opportunity.

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FOREST NURSERY PRODUCTION IN THE UNITED KINGDOM: CASE STUDY MAELOR NURSERIES LTD.

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Abstract

Forest policy in the United Kingdom does not list timber production as a main objective, despite the fact that the country is heavily reliant on imports of timber products. The level of new conifer planting has been much reduced over the last ten years; timber prices are very low due to the high rate of sterling; competition from imports is high; devolution plus the recent impact of foot and mouth disease, cumulatively provide an uncertain future for British forestry.

Production from British forest nurseries is directed towards commercial forestry, amenity and landscape, native broadleaf plantings, hedging and Christmas tree markets. Of the handful of larger wholesale nurseries that still remain, Maelor Nurseries Ltd is holding on to its position as one of the dominant nurseries in a much reduced and competitive industry.

Key Words

Forest industry, nurseries, production, quality, *Picea sitchensis*, forest ownership

In many respects, forestry in the United Kingdom (UK) represents a similar picture to that of the United States. In recent years there has been an emphasis shift in the way we view and manage our forests. As we become more aware of environmental issues as a nation, sustainability of our forest resources takes priority over timber production. Forest policy and management now reflect the change in objectives and the forest industry adjusts and adapts in order to operate within the constraints that this imposes. In recent years, investment in forestry has declined and as a result the industry has downsized. Production from forest nurseries has fallen and only a small number of them continue to operate. We strive for a happy medium between a commitment to safeguarding our environment while maintaining a viable forest industry for future generations.

UK FORESTRY

Forest cover in the UK stands at 11% of the land area or 6.9 million acres (Figure 1). In comparison, Finland has a forest cover of 65%, Sweden 60% and Norway 27% (Smith 2001).

The Forestry Commission (FC) is the government department responsible for the protection and expansion of the UK's forests. Within the FC are two executive agencies: Forest Enterprise and Forest Research. Forest Enterprise is entrusted with the management of the nations forest estate and Forest Research carries out research, technical developments and surveys.

The majority of the UK's forest cover is privately owned. Conifers make up the greater proportion of forest cover, with the private sector and FC managing similar proportions (Figure 2). Sitka spruce (*Picea sitchensis*) is the primary species of conifer being grown.

Although a compulsory restocking policy ensures that the restock market maintains reasonably consistent (Figure 3), the area of new conifer planting has fallen dramatically (Figure 4). Levels of nearly 60 thousand acres in the early 1980s have fallen to today's levels of 15 to 20 thousand acres. In 1919, the main aim of the newly formed FC was to create a strategic reserve of timber in case of war and so afforestation was a primary objective. In more recent years, the Dedication Scheme allowed private forest owners to manipulate taxation incentives, making forestry an attractive long-term investment. In the 1980s this scheme was suspended and a decline in new plantings to the present day levels was the result.

The broadleaf component dominates in the private sector as it does in those forests where timber production is not the primary objective. New planting of broadleaves has been maintained at a level of 20 to 30 thousand acres over the past five years.

Of the 50 million cubic meters of timber used every year in the UK, only 10 million are produced from UK forests. As a consequence, the UK is second in the world after Japan in terms of the importation of wood products. Most of the UK's sawn wood is imported from Sweden, Finland and Norway, with increasing quantities from the Baltic States. The level and source of timber imports is a controversial issue. With the economy as it stands, timber prices are low and it is financially more economical to import timber than to fell the UK's forests. The Scandinavian countries are widely recognised as producers of high quality timber and so this makes for a viable source. The UK is a nation of 60 million people, with a high currency and limited land resources. For it to be self-sufficient in timber production is unrealistic. At present, the pendulum has swung too far in the wrong direction and UK suppliers struggle to survive in a market over-run with imports of timber.

Present day forestry in the UK has shifted away from planting uniform blocks of conifers to sustainable forest management, which incorporates environmental assessments and a species mix. Environmental and biodiversity issues have become priorities over timber production. As quoted by the Director General of the FC, "every time we plant broadleaves on an acre of land we reduce its productivity in terms of timber production, while enhancing it in terms of biodiversity and recreation." In 1999, producers and users of British forest products formally launched a forest management audit scheme to increase the certification of sustainably produced timber. Even though the concept was widely recognised, the sawmills are not insisting on certified material in the present economy.

Forestry in the UK is very much grant led, with native broadleaf and pinewood planting schemes receiving a higher level of grant aid than conifer plantings. In line with the new forestry objectives, further grant aid is available where recreation and public access are also key issues. Devolution is a recent political and geographical split, resulting in assemblies or parliaments in England, Scotland, Wales and Northern Ireland. Along with the recent outbreak of foot and mouth disease, one can only predict what the changes in land use might be as a result. In Scotland, forestry is regarded as a primary industry. Therefore, in the wake of devolution and foot and mouth, there is a good chance that the level of forestry will increase. Certainly, with large areas of forest in Scotland due to be felled in 5 to 10 years, this is the time to be attracting markets and ensuring that processing facilities are in place for the timber.

Case Study: Maelor Nurseries Ltd

As the forest industry scales back, so does production from FC nurseries and the private sector. Only a small number of highly competitive nurseries remain, each concentrating on their specialisation and market edge to survive. Maelor Nurseries Ltd is one such private nursery, located near the Welsh border in central England on 435 acres of land. Maelor prides itself on bare root production for commercial forestry and hedging markets. The nursery grows up to fifty different species of conifer and broadleaf species combined, with various different stock types.

Production

A large proportion of Maelor's stock is aimed at commercial forestry, new planting and restock sites. Maelor is also at the forefront of producing broadleaf stock from British provenance seed sources. It is a priority within UK forestry to use

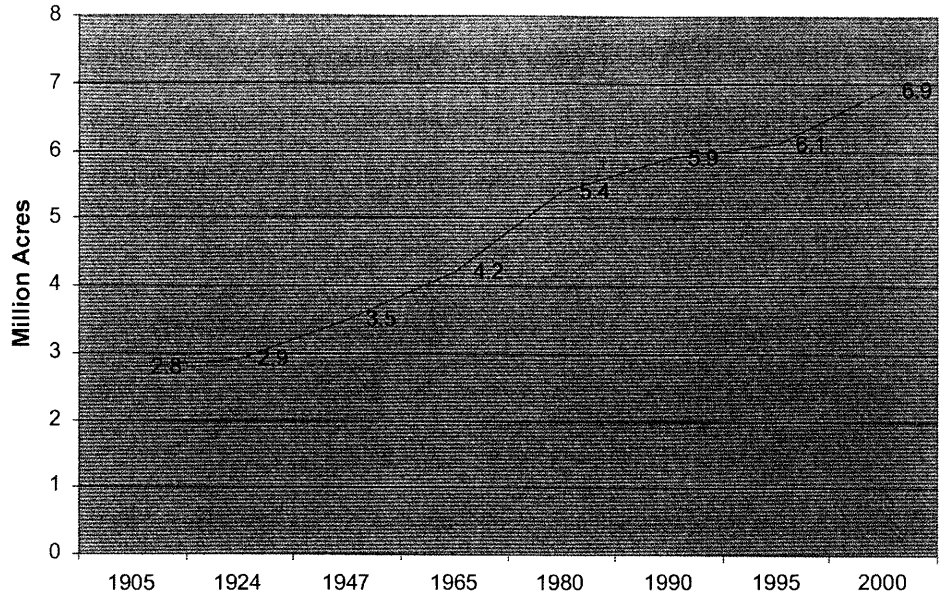


Figure 1. Forest cover in the UK (data from Smith 2001)

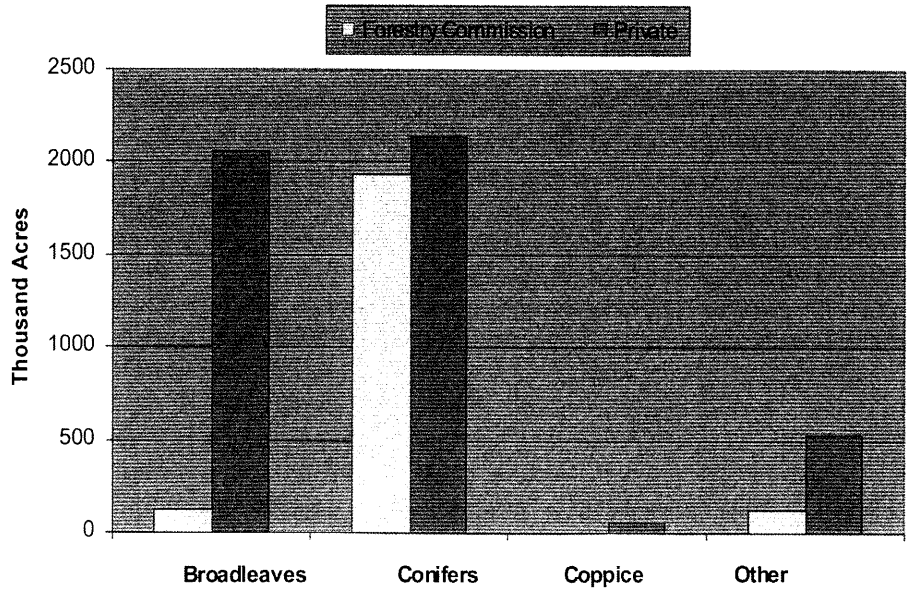


Figure 2. Area of forest, forest type and ownership (data from Smith 2001)

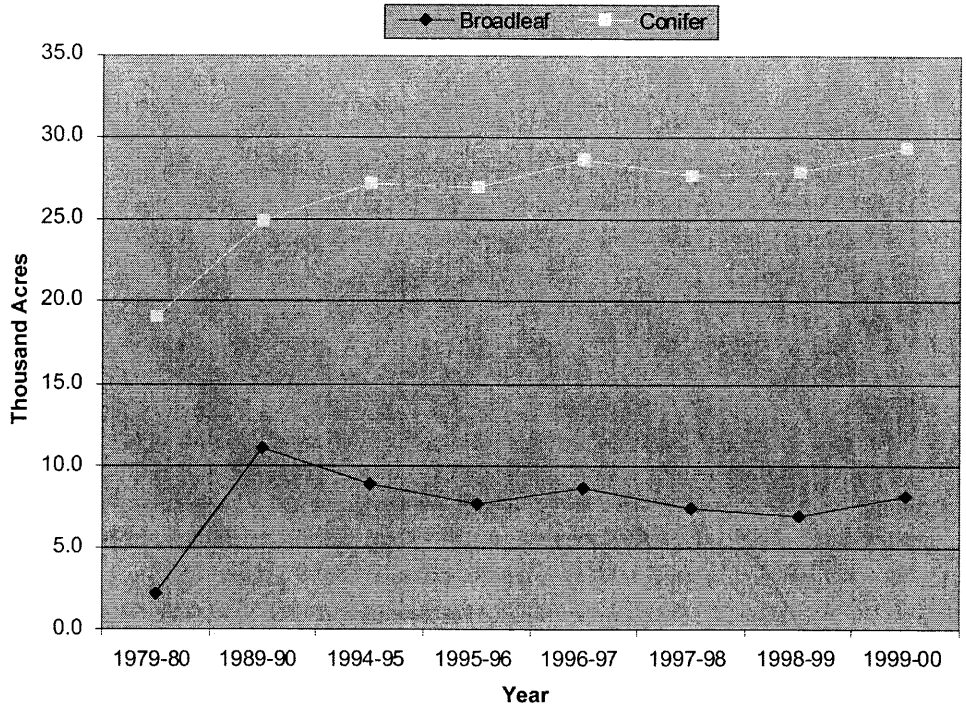


Figure 3. Area of restocking in the UK (data from Smith 2001)

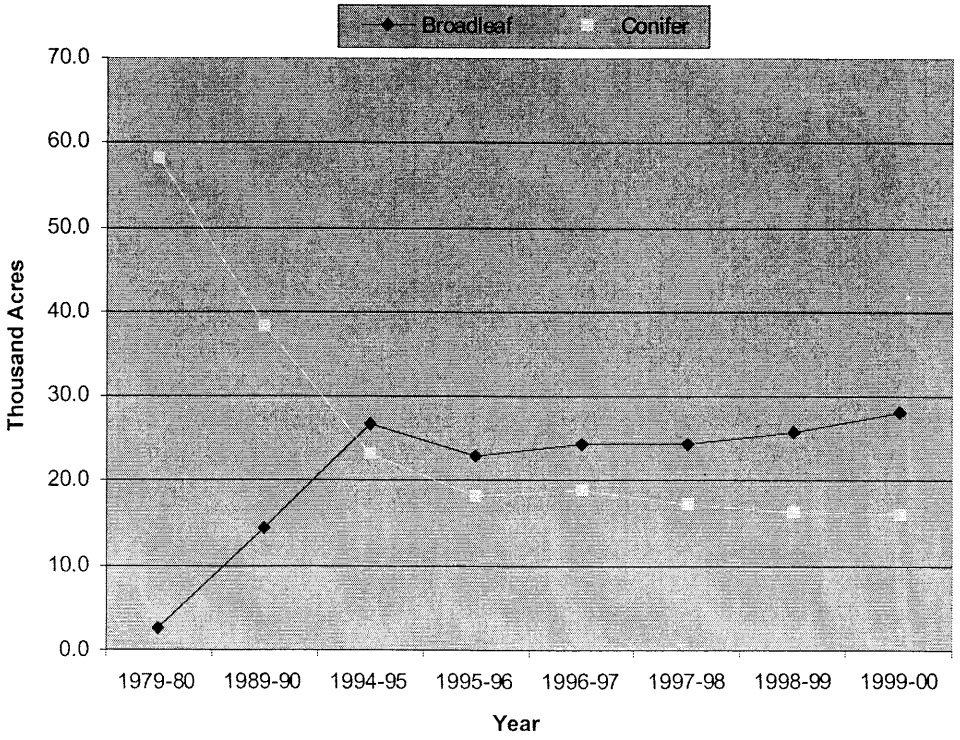


Figure 4. Area of new planting in the UK (data from Smith 2001)

native species of local provenance stock in planting schemes. Local provenance stock is best able to provide the maximum benefits to wildlife, adapt to local conditions and may provide a higher yield of timber. Using the UK seed zone map, collections of seed are organised throughout the UK. Much of the extraction, cleaning and treatment of broadleaf seed is carried out on site. In-house germination testing is carried out throughout storage and treatment of all seed.

Maelor's latest venture is with vegetative propagation, predominantly with selectively improved Sitka spruce (*Picea sitchensis*). The improved material offers a potential gain in vigour and in form over standard material, with these gains being widely recognised for use on commercial forestry sites. Improved Sitka spruce seed is available from FC seed orchards, but due to the inevitable delay in establishing orchards and harvesting seed, the production of vegetatively propagated material has taken precedence for many nurseries. The genetic base of the planting stock is maintained at a level as high as improved seedlings derived from seed orchards. Cuttings are taken from stock plants and rooted in poly houses before being transplanted out in the nursery.

Nursery Operations

Soil fumigation is carried out in the autumn and spring using metham-sodium. Conifer and broadleaf sowings commence in early spring as the weather dictates. Conifer sowings are broadcast rather than drill sown and grown for two growing seasons before being transplanted into rows. Many of the broadleaf species are drill sown and grown in the nursery bed until lifting for sale. Frost is a major threat to newly planted seedbeds and a fleece material is laid over metal hoops across the seedbeds to protect the seedlings.

Transplanting is carried out in spring, summer and autumn. Many seedbeds are lifted during the winter and the seedlings are held in cold storage until spring transplanting commences. The nursery utilises two main types of transplanting machines, the disc mechanism and belts depending on the stock type (Figure 5).

Pesticide applications are complex due to the variety of species being grown. Restrictions on the availability of approved chemicals and their usage is a constant concern. Inter-row spray applications (Figure 6), are frequently carried out to ensure improved efficiency of chemicals and to minimize crop damage.

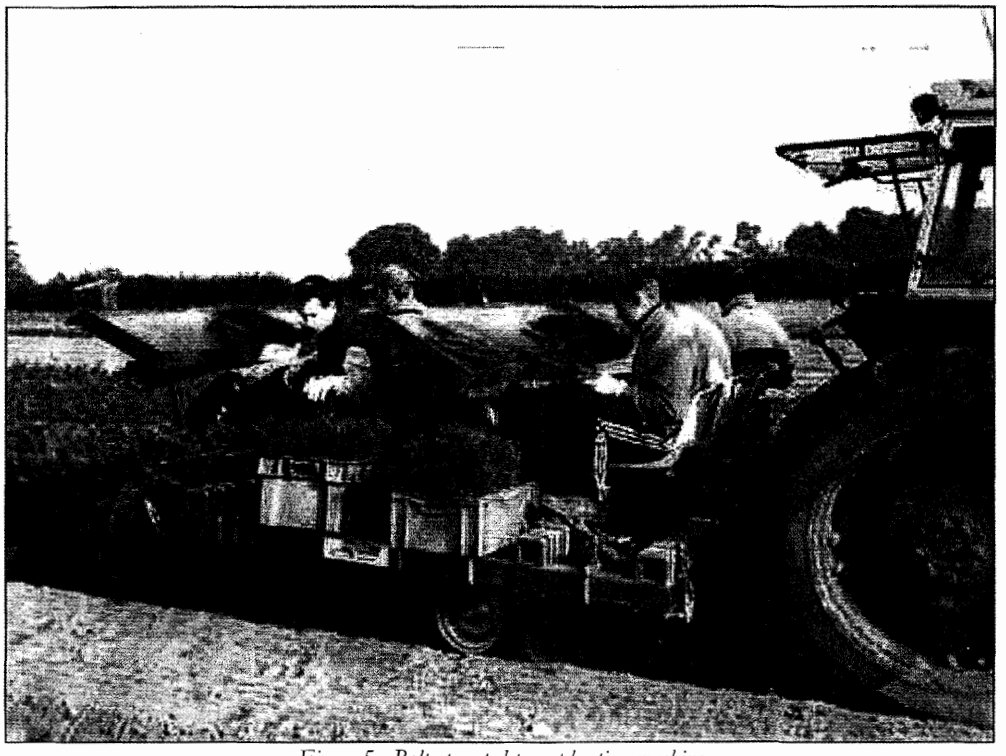


Figure 5. Belt operated transplanting machine



Figure 6. Inter-row spray applications

On average, the nursery receives 30 inches of rainfall per annum and irrigation is necessary during most growing seasons. Hydrants are located in the main seedbed growing fields and on-site reservoirs store water supplied from a local canal. Irrigation water is applied through retractable reels, which can cover up to 15 beds at a time.

Lifting commences in mid-October and is carried out largely with the use of machines. Lifting machines lift one row of stock at a time and are operated by a crew of four people. Labour is difficult to source and rates of pay are high, making machine lifting an economical choice (Figure 7). Lifting continues throughout periods of good weather and stock is placed into freezer storage until grading. Grading separates out stock in terms of height, form and root collar diameter. Once grading is complete, the stock is packed into co-extruded bags and freezer stored until shipping. The use of bar-coded labels on the stock allows for accurate stock control figures

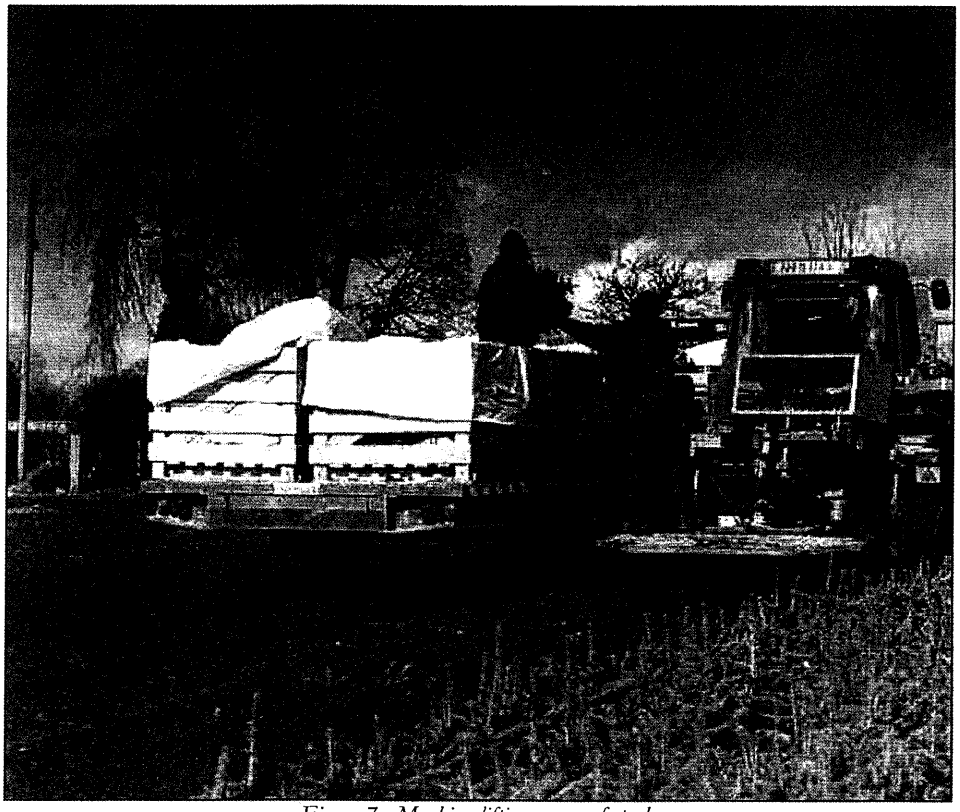


Figure 7. Machine lifting a row of stock

throughout the season. Large freezer stores provide temperatures of minus two degrees celsius and stock can be stored for up to six months without any detrimental effects on quality.

Quality

The production of a high quality product is a priority and Maelor incorporates various assurance methods in order to maintain quality throughout nursery operations. During the winter months, root electrolyte leakage (REL) tests are routinely carried out on stock to monitor physiological quality from lifting, grading, cold storage to shipping. The REL test provides our customers with a valuable guide to the expected survivability of stock at the time of shipping. The test can also provide valuable information on the level of dormancy of the stock. As part of Maelor's effort to ensure a quality product, the Company is accredited under ISO9002 Quality Management System. A comprehensive and fully audited Quality Manual, detailing nursery operations from seed collection, sowing through to shipping enforces this.



Figure 8. Root electrolyte leakage testing

Conclusion

The abandonment of a commercial core to the continuation of any industry has its dangers and one can only speculate over the future of the UK's forest industry as it tries to balance environmental issues with commercial production. The current level of planting is unlikely to significantly alter in the near future and nurseries have to evaluate their production in order to supply stock in line with demand. Over the last twelve months, several private nurseries have been forced out of business. Those that remain must stay focused and actively compete to sustain their market position. Maelor Nurseries Ltd sold its Scottish based site earlier this year and has reduced the main nursery site so that only the most productive areas of land are in use. With market awareness, a good team of people, the production of high quality products, and the continued support from major shareholders, the Company stands at the forefront of what lies ahead for the forest industry in the UK.

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SLOW RELEASE FERTILIZERS 101

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Rose, R. 2002. Slow Release Fertilizers 101 . In: Dumroese, R.K.; Riley, L.E.; Landis, T.D., technical coordinators. National Proceedings: Forest and Conservation Nursery Associations—1999, 2000, and 2001. Proceedings RMRS-P-24. Ogden, UT: USDA Forest Service, Rocky Mountain Research Station: 304-308. Available at: http://www.fcnanet.org/proceedings/2001/rose.pdf

Key Words

Native plant nurseries, forest nurseries, plantations, fertilizer types, fertilizer research

Slow release fertilizers have been in common use within the horticultural industry for decades. Probably the mostly commonly heard of product is Scott's Osmocote which has been around for a quite a long time. However, some time ago slow release fertilizers moved out of the potted greenhouse environment and onto golf courses, suburban lawns and bushes, and orchards. Slow release fertilizers are here to stay, but there still seems to be a lot of users who do not understand them.

The purpose of this paper is to: 1) demystify some of the characteristics of slow release fertilizers; 2) provide some useful information about the differences in a few products; and 3) offer up some generic advice on how best to utilize these fertilizers effectively. Believe it or not, slow release fertilizers are a daunting subject loaded with all sorts of interesting technologies. As with many products, the end user gets glowing product support brochures without ever seeing any of the research literature. Most of the product literature I have read is accurate. Too often the problems growers face with slow release fertilizers are associated with inexperience and ignorance of fertilizer technology in addition to operational experimentation. Maybe this little paper will lead a few nursery managers, growers, and conservationists to go to the library.

The term used in this paper will be slow release fertilizers even though many literature sources call them controlled release fertilizers or CRF. Delayed release might even be a better term. As you will read later, some slow release fertilizers are not very slow as the temperature goes up. Some products are not very controlled if they have been exposed to water vapor in storage. Some are hardly delayed after being mishandled. Rather than get into the semantics of the situation, slow release will be utilized throughout this paper.

Right from the start it needs to be clearly established that slow release fertilizers can be used with a vast array of plants. It is wrong to assume that these fertilizers are mostly suited to the greenhouse business. I have personally used them successfully in Taiwan with several native tree species with heavy soil in polybag containers—hardly the most ideal growing system. In actuality there is a whole frontier of opportunities to use slow release fertilizers effectively in native plant nurseries with a focus on restoration ecology and conservation. Slow release fertilizers have already started to find their way into plantation forestry. In my opinion the factor holding back the expanded use of slow release fertilizers into many arenas is the lack of a will to experiment after minor set backs.

THE PRILL

A good place to begin a discussion of slow release fertilizers is the tiny delivery system called the prill. The prill is the 2 to 3 mm wide particle that may be round or jagged looking that contains the fertilizer. It may be coated or non-coated. Not much thought is ever given to prills since it is so easy to view them as so many glass bead-like particles of a highly uniform nature. Actually, they are not that uniform at the micro level in that they can vary in size, vary in coating thickness, vary in weight, and vary in volume. Prills that are small tend to release faster than larger ones. A bag of slow release fertilizer contains a population of

prills. With all this variation, it is a foregone conclusion that fertilizer release is going to vary on a micro level as well.

Advantages and Disadvantages

Slow release fertilizers have specific advantages and disadvantages when examined as a class of fertilizers. It is through an understanding of these characteristics that the best operational practices can be developed. Not all nursery situations require or should utilize these fertilizers.

What are some of the advantages? This technology does a fine job of metering out nutrients over a period of time under controlled moisture conditions. Increased nutrient efficiency and utilization are the prime advantages. A prill right up next to the root under optimum moisture and temperature conditions can provide a very high dose of fertilizer right where the plant needs it. Leaching of nutrients can be greatly reduced. The product on a plant basis is not as expensive as perceived.

What are the disadvantages? Prills can be damaged by abrasion and fail to perform properly. Improperly stored prills can take on moisture and start the release process prior to use. Salt build up can occur under dry conditions or if the plants are not being irrigated properly. If there is a salt problem, it is impossible to remove the fertilizer from the media. Salt toxicity at out planting can become a problem if the plants are held over in cold storage for too long. There is no easy means by which to determine if the product is damaged or may prove ineffective in some way.

It is not a matter of comparing advantages to disadvantages that should determine the use of slow release fertilizers. One can find equal numbers of each upon which to base a decision or decide to bias one over the other. The best advice is to start to carefully and methodically test out certain types of fertilizers over a range of concentrations. Keeping good records is the first step in figuring out what will work best under a given set of circumstances. However, before getting into experimentation, it is best to get a general understanding of some of the different kinds of slow release fertilizers.

Types of Slow Release

Think of slow release fertilizers as coming in several varieties. There are inorganic, organic, synthetic inorganic, and coated forms. Of the coated forms, there are polymer and resin coated, but there have been lots of different kinds of materials that have been used as coatings.

Inorganic: An example of an inorganic slow release fertilizer was MagAmp or magnesium ammonium phosphate. Potassium analogues have also been made.

Organic: Organics have been around for thousands of years starting with animal manure, animal byproducts like hoof and horn, fish, fish emulsions, seaweed, bone meal, human sewage sludge, and all sorts of composted combinations of bark, wood, and plant materials.

Synthetic Organic: Ureaform is the reaction of urea with formaldehyde in the presence of a catalyst. Ureaforms consist of methylene urea polymers that vary in chain length and the release characteristics are controlled by the ratio of urea to formaldehyde (Hauke 1985). A good example is Nitroform. IBDU or isobutylidene diurea fits in with this general group.

Coated: All sorts of products have been used as coatings such as sulfur (sulfur coated urea), polymer-coated NPK (Osmocote, Agriform), and petroleum-coated (Nutricote).

Rate and Pattern of Release

Mode of Release

All growers understand readily soluble fertilizers. Those are the ones that go into solution quickly and are immediately available. Everyone has heard of ammonium nitrate and mixes like Peters 20-20-20. Surprisingly, there are all too many practitioners of the nursery arts who are not quite sure about urea. Urea is not a slow release fertilizer and is completely soluble. Once applied, the urease enzyme (present in organic matter and plant tissue) in the presence of water hydrolyzes the compound to ammonium, carbon dioxide and ammonia gas. The ammonium is then converted to nitrate via nitrobacter bacteria. The nitrate is absorbed by the plant. Ammonium at media or soil pHs > 7 lead to conversion to ammonia gas and escape into the atmosphere. At pHs < 7, nitrogen converting bacteria turn it into nitrate. As an aside, free ammonia penetrates plant cells very quickly and is quite toxic (Bunt pg102 1988). Since so many slow release fertilizers have urea in them, this is a good reaction to understand.

Without getting too complicated here, slow release fertilizers give up their nutrients due mostly to two interlocking factors: moisture and temperature. Bacteria do play a role with some products, but even the bacteria need moisture and temperature in order to function. Generally, the higher the temperature and the more moisture available, the faster the release takes place. The coating also makes a big difference as will be discussed further in this paper.

One of the little known "secrets" of release in slow release fertilizers is that the time to total release is figured out on the basis of 70 F. The manufacturers use this temperature as a guide and it works well in the context of horticultural operations (Cabrera 1997). However, this information is not worth much in most field situations.

Sources of Variation in Release

Variation in release comes from several commonly understood processes: 1) abrasion: when the prills rub against soil or sand in mixes, too much the coating gets damaged; 2) thickness of coating: while coating of prills is a fine art, there is still variation in thickness which can alter the degree to which prills release; 3) moisture: if bags of some slow release fertilizers are left open portions of the material can start to hydrate and will release sooner than others once they are placed in the media (Kelly et al 1998); and 4) age: the longer the prills are stored the more likely their characteristics are likely to be adversely impacted by moisture, temperature, and handling.

Coatings

One of the first coatings was sulfur, which is where sulfur-coated urea got its name. Many coatings were tried in the past, including waxes, oils, plastics, and resins. Most manufacturers refer to their products as being polymer coated, when in actuality the coating may be a resin or polyurethane. The word polymer merely refers to a compound of high molecular weight derived from a host of smaller molecules. Some polymer coatings need release controlling agents like ethylene-vinyl acetate and surfactants to allow for the proper diffusion of nutrients. Tremendous research dollars are spent every year on attempts to discover polymers for all sorts of uses, not just those associated with slow release fertilizers. Unfortunately, the ultimate coating that will release nutrients on command has yet to be discovered.

Some Common Products

The following is a short synopsis of fertilizer descriptions. These are all interesting and useful products. No one product is endorsed over another. The purpose here is to provide some useful information about each that may help growers and nursery managers to safely utilize these products.

Osmocote

This product has been in use for a very long time and is practically a household name. The name was likely derived from the concept of osmosis through a coating, which is exactly what polymer coated slow release fertilizers do. The coating uses an alkyd resin coating technology which "involves coating a soluble fertilizer core with a thermoset copolymer of dicyclopentadiene and glycerol ester (linseed oil) dissolved in an alphatic hydrocarbon solvent" (Goertz 1993). The thicker the coating, the longer the release will take to occur. The prill gets wet and then begins to expand. Once the expansion begins the process of release is irreversible. As the pores in the coating open up, the saturated solution inside begins to move out of the prill into the surrounding media or soil solution. Osmocote tends to release more quickly as the temperature begins to rise, assuming similar levels of moisture. There are numerous products on the market. There are formulations and coatings that are said to be able to release for up to 18 months.

O.M. Scott and Sons Co (Scotts) makes a latex coated product designed for high temperature growing conditions.

Polyon

This is the trade name given to the polyurethane coating on Simplot products under the brand name Apex. Release is by osmotic diffusion. It is an interesting process by which the product is made. It is called reactive layer coating or RLC. Two reactive monomers are applied to the fertilizer, which form an ultrathin membrane. For technical details refer to Goertz (1993). In short, two solvent-free liquids react, polymerize right on the substrate fertilizer *in situ* in a drum and form a polyurethane coating. Production costs are lower

using this system. Polyon is supposed to be less temperature dependent as well when it comes to release.

Nutricote

This product uses the technology from the Chisso-Asahi Fertilizer Company in Japan. The coating is a thermoplastic resin such as polyolefins, poly(vinylidene chloride), and copolymers (Goertz 1993, Hauck 1985).

Ureaform

This product is a synthesis of urea and formaldehyde. There are numerous ureaform products on the market. Basically, ureaforms are white and odorless solids. The product is made up of methylene urea polymers. Ureaforms are broken down by soil bacteria. The shorter-chained polymers are water-soluble and break down quickly, while the long-chained polymers take much longer to break down. One product is Nitroform from Nu-Gro Technologies, Inc. Some 71% of Nitroform is water-insoluble nitrogen.

IBDU

This product has a name no one can pronounce so they call it IBDU. It comes about from the condensation of urea and isobutyraldehyde, which is less than .1% soluble in water. The commercial product is around 31% nitrogen. Some commercial products with IBDU are Woodace and Agriform Pellets.

Combinations of Slow Release

It stands to reason that with such an array of immediately soluble and long term slow release fertilizers, the possibility exists to blend them for optimum nutrient availability. To date, not a lot has been published on this subject although it is most likely that many growers have worked out various combinations that work well under specific local conditions.

Research Challenges

Slow release fertilizers have been used for decades in the horticultural growing environment. However, the application of these products to forest trees and native plants has been very slow in coming. It is time that this situation changed and growers began the process of experimentation on a larger scale. There will be many failures that will go unreported along with stunning successes that everyone will hear about at meetings. What is called for is a more open effort to discern the best technologies for given nursery and field situations by species.

Here are some ideas to work on in the future.

- Finding the right fertilizer combinations for any given set of conditions. It makes sense that we should be able to put a slow release fertilizer into the growing media at the time of sowing and have the fertilizer start to release some 14 months later at the time of out planting. We might also want three-month slow release fertilizers that work up to the time of hardening off and then quit, followed by another product that would release for a month during root development in the fall.
- Finding the right fertilizer combinations for specific species. We already know that some species are likely to be adversely impacted by various nutrients at high dosages. Some species are going to be more salt tolerant than others as well.
- Finding ways to deal with dry climates and alternating wet and dry conditions. Slow release fertilizers suffer from the same problem as readily soluble fertilizers when the ground or growing media gets dry. Salt levels rise dramatically in the field as soil moisture drops. What is needed is to develop fertilizer recipes for out planting situations, whether it is forest trees or native plants, as part of a restoration project after a fire. Soil moisture by slow release fertilizer studies could tell us a lot about what to do and not do in field situations.
- Finding ways to get nutrients other than Nitrogen into seedlings after out planting. Nitrogen is not the only nutrient that plants need. While nitrogen is very important to plant growth, phosphorus and potassium are also important. Getting more phosphorus into plants can be a real problem even when using slow release fertilizers, since phosphorus is too often tied up very quickly in some soils.

Summary

We have a lot of exciting opportunities ahead where slow release fertilizers are concerned. There are multitude of species and fertilizer products to try out in the nursery and the field.

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Percussion as an Alternative Scarification for New Mexico Locust and Black Locust Seeds

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Abstract

Hot water and sulfuric acid soaks are traditional treatments for seeds of many temperate woody legumes, including locusts. However, these scarification techniques often produce inconsistent germination. Percussion scarification, where seeds are repeatedly propelled against a hard surface, was compared with hot water scarification to evaluate treatment efficacy for New Mexico locust (*Robinia neomexicana*) and black locust (*R. pseudoacacia*) seeds. In the hot water treatment, seeds were placed in a 98 °C water bath, which was immediately removed from the heat source. For percussion scarification, seeds were placed in a soil sample tin and agitated in a paint shaker for 1, 2, 3, 4, 5, or 10 minutes. All treatments, including the control, were followed by 24-hour water soaks. Hot water baths resulted in 56% and 41% germination for New Mexico locust and black locust respectively. For both species, nearly all durations of percussion increased germination over the hot water treatment. Percussion durations of 4, 5, and 10 minutes for New Mexico locust and 3, 4, and 5 minutes for black locust resulted in at least 90% germination. Traditional scarification treatments randomly degrade the entire seed coat, which can lead to tissue damage during water uptake. Percussion scarification specifically weakens the strophiole, the natural source of water entry to the seed in papilionoid legumes. Following percussion, imbibition is controlled through the strophiole and underlying tissue is protected.

Key Words

New Mexico locust, black locust, scarification, percussion, germination

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Locust trees (*Robinia* spp.) are aggressive pioneer species that quickly colonize disturbed land, fix atmospheric nitrogen in the soil, and stabilize slopes that are prone to erosion (Klemmedson 1994; Ashby and others 1985) (Figures 1, 2). Recognition of these attributes has contributed to increased demand for locusts in reclamation projects. Locust seeds, however, exhibit physical dormancy, where a thick seed coat prevents the movement of water and gasses to the embryo (Leadem 1997).

Sulfuric acid or hot water soaks have traditionally been used to break seed dormancy in macro-propagation of locusts. Many growers are moving away from the use of sulfuric acid in treating locust seeds (Dreesen and Harrington 1997). In addition to being dangerous, acid soak durations must be specifically correlated to seed lot (Young and Young 1992). Collections of native seed can vary tremendously in seed size, seed weight and hard seededness, and so on. This variability limits the utility of sulfuric acid soaks, as even within a given lot, some seeds may be over-treated and damaged, whereas others are under-treated and fail to imbibe (take up water). A survey of southwestern container growers indicates that hot water baths are currently the most common scarification method for locust seeds (Hine and

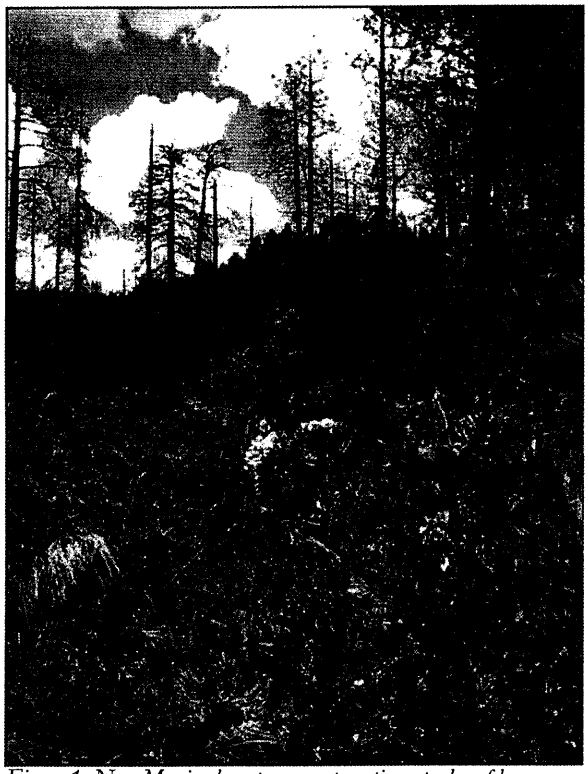


Figure 1. New Mexico locust crown-sprouting at edge of burn near Los Alamos, NM—one year after Cerro Grande fire.



Figure 2. New Mexico locust colonizing road cut.

Figure 2. New Mexico locust colonizing road cut.

others 1997). However, hot water baths can also produce inconsistent germination (Lin and others 1996).

Percussion scarification, where seeds are repeatedly propelled against a hard surface, is an alternative dormancy-breaking method that has proven successful in legumes related to locusts (Hamly 1932; Barton 1947; Mayer and Poljakoff-Mayber 1982). We compared this alternative treatment to hot water scarification to evaluate treatment efficacy for New Mexico locust and black locust seeds.

Materials and Methods

Commercial New Mexico locust seeds (Western Native Seed, Coaldale, CO) were collected during fall 2000 in Huerfano County, CO. Black locust seeds were collected during September 2000 from Taos County, NM by harvesting ripe pods from several trees at a distance of up to 3 meters from ground level. Black locust seeds were allowed to air-dry for 3 weeks, and were threshed and separated from large chaff using a greenhouse fan. A Dakota Blower was used to remove fine chaff from both seed lots. Seeds were stored at 2 to 4 °C until the germination study was conducted in March 2001.

This study compared hot water scarification with percussion scarification using treatment and species as experimental factors. Along with a control, scarification treatments included immersion of seed in boiling water as well as percussion durations of 1, 2, 3, 4, 5, or 10 minutes. Four 100-seed samples were used to test each species by scarification treatment combination.

For the hot water treatment, test tubes were filled with 30 mL water and placed in a water-filled beaker (Figure 3). The bath was raised to boiling (~98 °C at Las Cruces, NM elevation of 1,300 meters). Each 100-seed replicate was placed in a test tube, and each test tube was immediately removed to cool at room temperature.

Percussion scarification was implemented using a pneumatic paint shaker (Central Pneumatic) (Figure 4). This allowed standardization of treatment intensity. Compressed air pressure was maintained at 80 psi $\pm$ 5 psi (530 kPa $\pm$ 30 kPa), resulting in approximately 350 oscillations per minute. Each 100-seed sample was placed in a 4 oz soil tin for shaking. To maximize lateral



Figure 3. Hot water bath.



Figure 4. Paint shaker set-up.

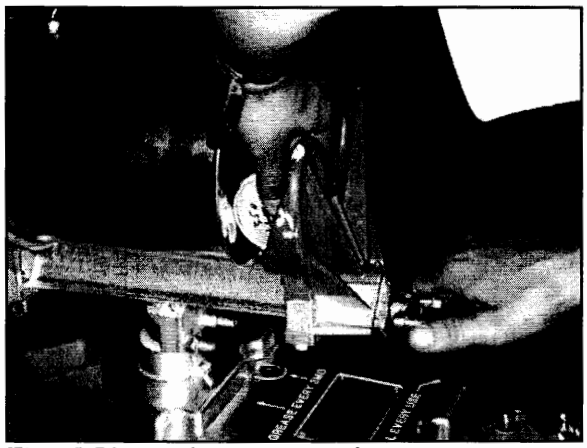


Figure 5. Placing soil tin containing seeds at end of paint shaker arm.

Figure 4. Paint shaker set-up.movement of the paint shaker, a paint can was used as a spacer to place soil tins at the end of the shaking arm (Figure 5). This allowed shaking to occur at the greatest distance from the pivot point (fulcrum). Following all treatments, including the control, seeds were soaked for 24 hours in distilled water prior to plating out.

Germination was evaluated on lab benches at room temperature. Each replicate of seeds was placed in a 10 cm petri dish on moistened filter paper, with humidity maintained by enclosing the petri dishes in ziplock bags. Germination was monitored daily for 14 days, in accordance with International Seed Testing Association standards for *Robinia* species (ISTA 1999). Germination was defined as protrusion of the radicle from the embryo by at least 1 mm.

Categorical Analysis of Variance using Proc Catmod (SAS Institute 1989) was used to determine treatment differences in germination percentages for each source. This procedure is an extension of a Chi-square test of homogeneity using the natural log of the ratio of germinated to non-germinated seeds for each treatment. P-values less than 0.05 were considered significant. A limited set of pairwise-comparisons was conducted to compare treatment means using a conservative alpha value of 0.05 divided by the number of comparisons.

Results

Percussion maximized germination for both New Mexico locust and black locust. Figure 6 shows three germination response levels for New Mexico locust. First, there was a low response in the control, indicating a dormant seed lot. The hot water treatment and one-minute duration of percussion share a second, intermediate response. Germination was highest at percussion levels from 2 to 10 minutes.

The representative percussion treatment produced the steepest germination curve, indicating the fastest germination rate (Figure 7). The hot water treatment produced an intermediate curve, or relatively slower germination rate. The control curve was very flat, indicating the slowest germination rate for New Mexico locust.

Control seeds germinated poorly for black locust as well (Figure 8). Hot water scarification improved germination over the control, but all levels of percussion improved germination over hot water. The optimal durations of percussion treatment were bracketed, with a significant increase from the 1 to 2 minute percussion level, a high germination response from 2 to 5 minutes of percussion, and finally a significant decrease at the 10-minute level. This drop-off suggests that 10 minutes of percussion over-treats seeds from this lot of black locust.

The representative percussion treatment also had the fastest germination rate for black locust (Figure 9). The hot water curve is somewhat flatter, indicating a slower germination rate. The control curve is very flat, indicating a slow germination rate.

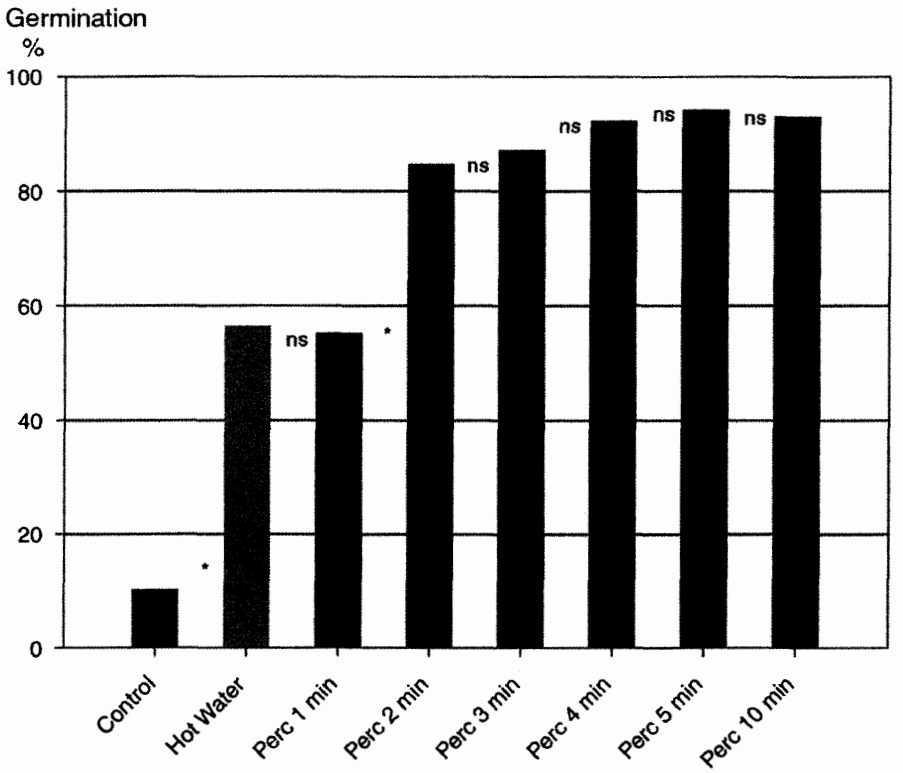


*Figure 6. Effect of scarification treatments on germination percentage for New Mexico locust. ns = no significant difference between adjacent treatment bars. * = significant difference at* $\alpha = 0.0045$ (0.05/11).

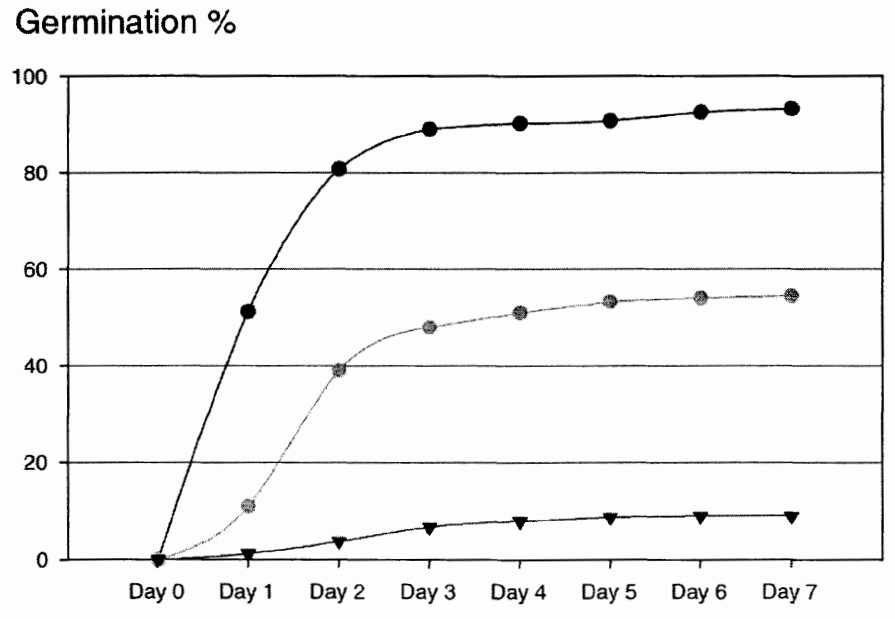


Figure 7. Effect of scarification on germination rate for New Mexico locust. Only 7 days of the 14 day study are shown. Five-minute percussion curve representative of 2 to 10-minute treatment durations. Germination rate defined by slope of the curve—the increase in germination with increase in time.

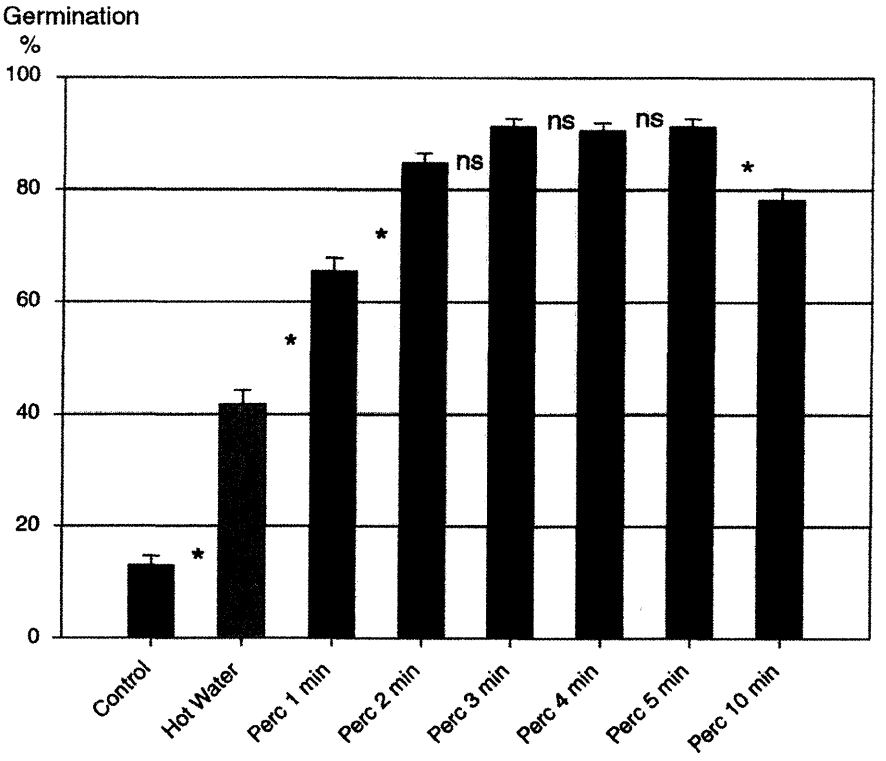


*Figure 8. Effect of scarification treatments on germination percentage for black locust. ns = no significant difference between adjacent treatment bars. * = significant difference at a = 0.0045 (0.05/11).*

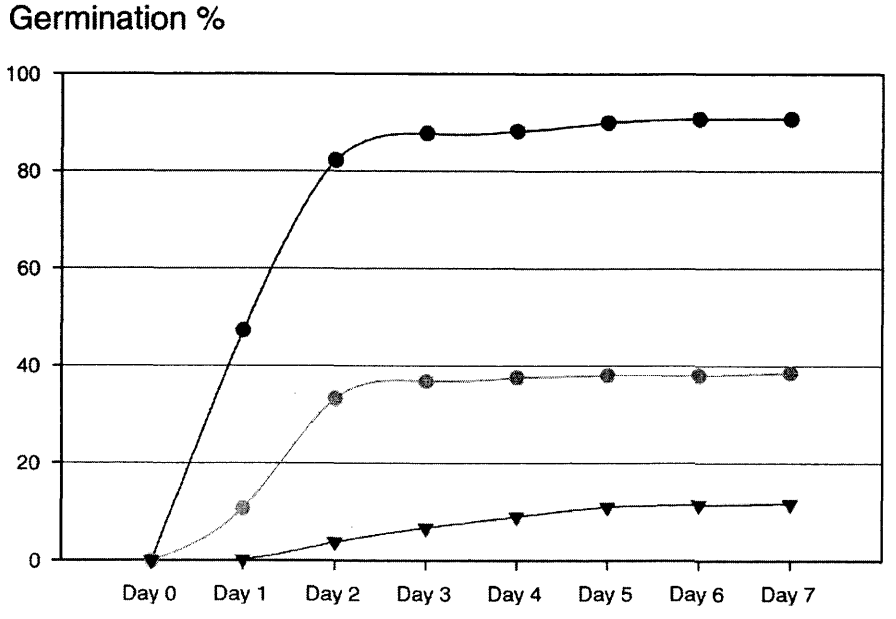


Figure 9. Effect of scarification on germination rate for black locust. Only 7 days of the 14-day study are shown. Five-minute percussion curve representative of 2- to 5-minute percussion durations. Germination rate defined by slope of the curve—the increase in germination with increase in time.

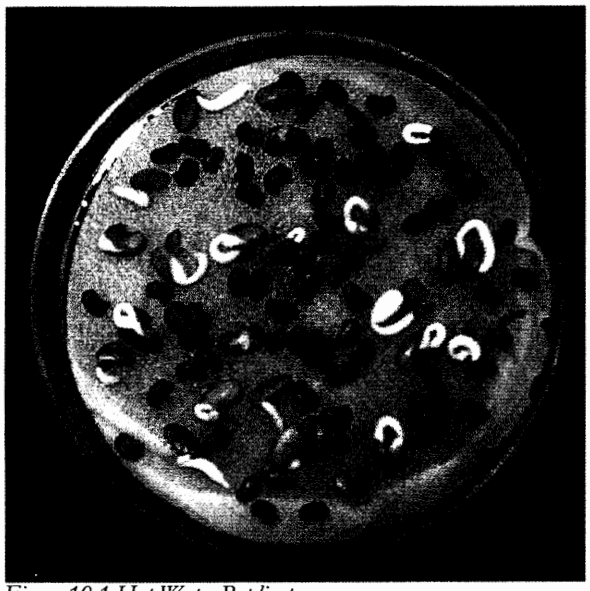


Figure 10.1 Hot Water Replicate.

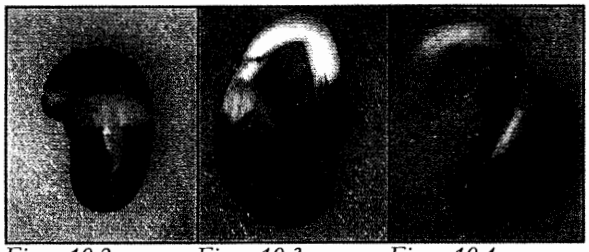


Figure 10.2 *Figure 10.3* *Figure 10.4*

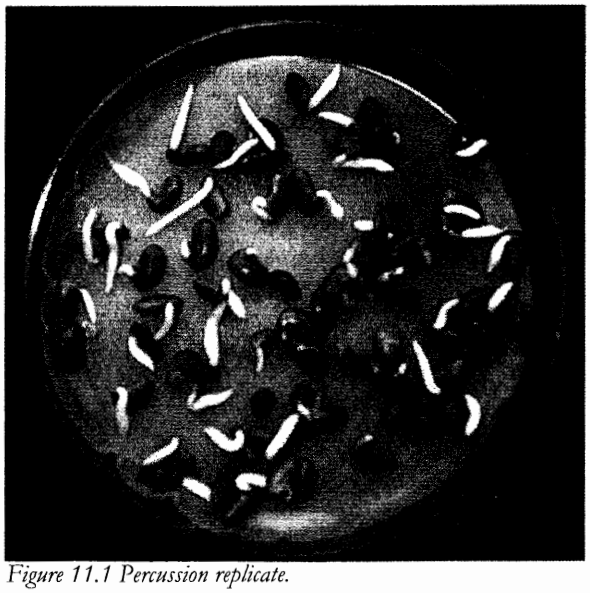


Figure 11.1 Percussion replicate.

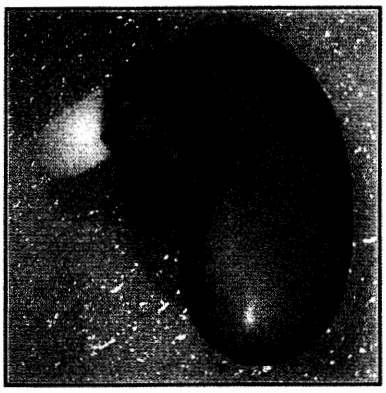


Figure 11.2

A qualitative difference between hot water and percussion-treated seeds was also observed. Along with healthy germinants, the hot water treatment produced over-treated seeds (Figure 10.1).

Examples of damaged germinants include seeds where the radicle did not elongate (Fig 10.2), seeds where the radicle elongated but was delayed in freeing itself from the seed coat (Figure 10.3) and seeds where the radicle broke off completely from the embryo (Figure 10.4).

In addition to these examples of over-treatment, there were numerous small, dark seeds that failed to imbibe water. For percussion treatment, nearly all seeds took up water (Fig 11.1). Germination was rapid and uniform, with little damage evident (Fig 11.2).

To summarize, both New Mexico locust and black locust seed lots were dormant. The standard hot water scarification treatment improved germination, but only to 56% and 41% for New Mexico locust and black locust respectively. Nearly all percussion durations improved total germination as well as germination rate over the hot water treatment. Germination was very high, over 90%, for percussion durations of 4, 5, and 10 minutes for New Mexico locust and 3, 4, and 5 minutes for black locust.

Discussion

Papilionoid seeds have a specific anatomical feature known as the strophiole, or lens—the natural site of water entry to the seed (Hamly 1932). The strophiole is located on the cotyledonary lobe of a locust seed (Figure 12). When a papilionoid legume seed is percussed for the appropriate amount of time, repeated hits on the integrated seed coat loosen the constrained

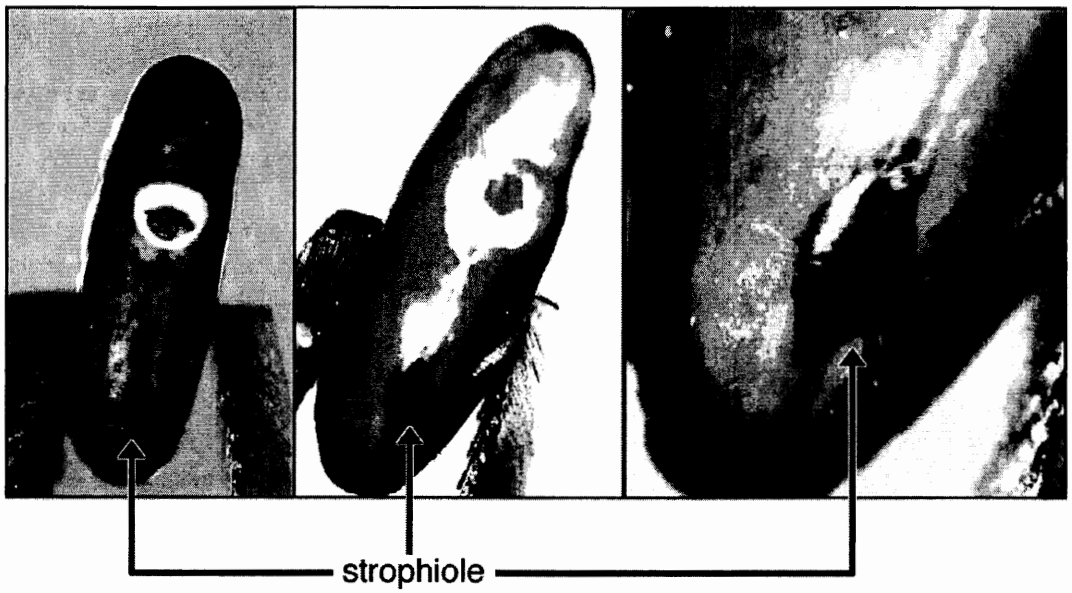


Figure 12. Strophiole of unimbibed New Mexico locust seed (left) and following water uptake (center, right).

cells of the strophiolar region, without excessively damaging the rest of the seed coat (Ballard 1976).

When a percussed seed is soaked, water enters exclusively through the strophiole in a controlled manner (Kelly and Staden 1987). This regulated entry of water to the embryo is associated with even pressure on underlying seed tissues. This contrasts with seeds that have been hot water or acid scarified, treatments that can randomly degrade the seed coat. Unlocalized cracks in the seed coat can promote irregular water uptake associated with uneven pressure on underlying seed tissues and subsequent seed damage.

Papilionoids are the largest subfamily of legumes, covering almost all legumes occurring in temperate climates (Baskin and Baskin 1998). As with New Mexico locust and black locust, these legumes often play an integral role in the revegetation of disturbed lands. Developing superior scarification methods to the standard hot water and acid treatments should facilitate the use of these legumes in restoration projects.

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INFLUENCE OF SITE PREPARATION AND STOCK SIZE ON THE ESTABLISHMENT OF ARIZONA CYPRESS PLANTINGS IN THE MIDDLE RIO GRANDE REGION

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Abstract

Establishment of tree plantings in arid and semi-arid regions where available irrigation water is limited is often costly and problematic. This study examined the effects of site preparation, specifically V-ditching and use of synthetic weed barrier alone and in combination, and stock size based on container volume on early, 1- and 6-month, mid, 12- and 15-month, and late, 72-month, survival and height growth of fall planted, Arizona cypress (*Cupressus arizonica*) seedlings planted in Los Lunas, New Mexico. The study was installed at the New Mexico State University Los Lunas Experiment Station in October of 1994. Seedlings were planted by hand using an auger. Immediately following planting the study site was irrigated with 7.5 centimeters of irrigation. Seedlings received no further supplemental irrigation. The effects of both site preparation and stock size became discernable only after 12 months. In general, survival was improved with site preparation with the 12- and 15-month survival averaging 80% for the V-ditch alone and in combination with weed barrier, compared to 55% for the control group. After 15 months, the two larger stock sizes evaluated, 262 ml and 656 ml container volumes, had survival averaging 80% compared to the two smaller container sizes, 115 ml and 164 ml whose survival was averaging 64%. After 72 months, the 262 ml container size had the greatest survival at 62% across the four site preparation treatments. The combination of the weed barrier/V ditch site preparation treatment and the 262 ml stock size yielded the greatest survival after 72 months, 86%. After 72 months, there was little difference in survival between site preparation treatments. The use of weed barrier as a site preparation treatment consistently improved height growth from the 12-month measurement period until the 72-month measurement period. The 262 ml container size consistently had the greatest height growth from the 15-month measurement period through the 72-month measurement period. These results indicate it is possible to establish trees in semi-arid environments when using appropriately sized stock in conjunction with appropriately prepared sites.

Key Words

Container stock

Most New Mexico farms are individually or family-owned and approximately 60% have annual revenues less than $10,000 (Mosbacher and Darby 1987). Agricultural output from New Mexico is primarily produced in arid and semi-arid conditions with limited water availability and highly erodible soils. One mechanism that can improve the conservation of land and water resources and enhance overall agricultural productivity is using windbreaks or shelterbelts. However, establishing tree windbreaks in the southern Great Plains and the southwestern United States can be problematic due to high costs and/or poor tree survival.

Several factors can influence the success of tree plantings in the southwestern U. S., including site preparation methods and type of planting stock. Poor site preparation and post-planting maintenance have been significant contributors to planting failures in the Great Plains (Nickerson 1990). The influence of planting stock size on outplanting performance has been well investigated for bare-root stock (Mexal and Landis 1990); however studies on the influence of stock type on outplanting performance are not as abundant.

A recommended approach for windbreak establishment in arid and semi-arid regions of New Mexico involves planting container grown seedlings in a prepared V-ditch covered with a woven weed barrier and providing supplemental irrigation following planting. Although this approach helps ensure survival during periods of drought, it is cost prohibitive for most landowners.

This study examined the influence of four site preparation techniques and four planting stock sizes on Arizona cypress (*Cupressus arizonica*) windbreak establishment in the Middle Rio Grande Valley agricultural region. Site preparation treatments were V-ditch, weed barrier, V-ditch and weed barrier, and control. Arizona cypress grown in four container sizes, 115, 164, 262, and 656 ml root volume, were used to evaluate site preparation and planting stock size treatments.

Materials and Methods

Arizona cypress seedlings were propagated at the New Mexico State University Forestry Greenhouse in Las Cruces, New Mexico under a standard production regime described by Harrington (1991). Four container sizes were used to obtain four stock size treatments: 115 ml Ray-Leach Cone-tainer, 164 ml Ray-Leach Cone-tainer, 262 ml Deepot, and 656 ml Deepot (Steuwe and Sons Inc., Corvallis, Oregon).

The planting site was located at the New Mexico State University Los Lunas Agricultural Experiment Station in Los Lunas, New Mexico. Prior land use for this plot was a four-wing saltbush (*Atriplex canescens*) seed production field from 1979 through 1994. Soil texture was a sandy clay loam (53% sand, 20% silt, and 27% clay).

Four site preparations evaluated in this study were a 2-meter wide V-ditch, a 2-meter wide synthetic weed barrier, a 2-meter wide V-ditch with a 2-meter wide synthetic weed barrier, and an undisturbed control. The synthetic weed barrier used in this study was a tightly woven synthetic burlap, which allowed water penetration but restricted weed growth. In the weed barrier alone plot, existing vegetation was mowed using a tractor mounted rotary mower. Residual saltbush stems and bushes were pulled to reduce the amount of air pockets between the weed barrier and the soil surface. After seedlings were planted, the weed barrier was laid over the planting area and incisions were made in the weed barrier and the seedling shoots pulled through the opening. A V-ditch is a shallow (10 to 15 cm deep) trench with two tapering sides, each approximately 1-meter wide. Seedlings are planted in the bottom of the trench. The V-ditch functions by directing the surface flow of water during heavy rain events to the bottom of the trench. The V-ditch treatment was installed using a tilting blade on a three-point hitch of a farm tractor.

Each site preparation by seedling size treatment consisted of an 11-meter long by 2-meter wide plot. Ten seedlings were planted in each site preparation by container size treatment combination. Seedlings were planted using a hand-held power auger with 7.5 cm diameter bit. Following site preparation and planting, the entire planting site received 7.5 cm of flood irrigation. No further irrigation was performed. Seedlings were planted in early October 1994.

Survival and shoot height were measured at 6, 12, 15, and 72 months following outplanting. Survival was recorded as either dead or alive. Shoot height was measured to the nearest centimeter using a graduated plastic pole. Relative shoot height was computed by subtracting a seedling's height at time of planting from height at 72 months, and then dividing by height at planting.

The experimental design was a randomized complete block design with three blocks for each planting date by site preparation combination. The response unit was the individual seedling and the experimental unit was the average of the ten-tree row plot per treatment combination. Growth and survival data were analyzed with a general linear model (PROC GLM, SAS Institute, 1999). Means were compared using Tukey's Studentized Range (HSD) Procedure, which controls experimentwise

error rates. Alpha values (α) of 0.05 or less were considered significant.

Results

Survival

Stock size did not influence 6 month survival but did influence survival at 12 and 72 months (Figure 1). At 12 months after planting, seedlings grown in the 164 ml containers had lower survival, 68%, compared to those produced in the other three sizes (mean = 86%). Survival decreased among seedlings regardless of container size from 12 to 72 months, but the amount of variability associated with the mortality increased in the seedlings produced in the 115 ml containers such that no difference between these seedlings and those produced in the 164 ml containers could be detected. At 72 months after planting, the seedlings produced in the 164 ml containers continued to exhibit lower survival (35%) than either those produced in the 262 or 656 ml size containers (> 50%), but was not different than seedlings produced in the 115 ml containers (45%).

As was the case with stock size, differences in site preparation treatments were not detected until the end of the first growing season (12 months). After 12 months, survival among the control, weed barrier, and weed barrier/V-ditch site preparation treatments was similar, while the V-ditch treatment had greater survival (92%) than either the control or weed barrier plots (Figure 2). Of all treatments, only the weed barrier/V-ditch treatment had greater survival (55%) than the untreated control, which had 35% survival at 72 months. Survival within the two less intensive treatments (control and V-ditch) declined more rapidly after 12 months than within the two weed barrier treatments. Mortality in the weed barrier treatment was less during the 12 month through 72 month interval than in non-weed barrier treatments (Figure 3). Trees within the V-ditch treatment had the highest mortality from 12 to 72 months comparable to the control mortality rate but higher than the mortality rates in the two weed barrier containing treatments.

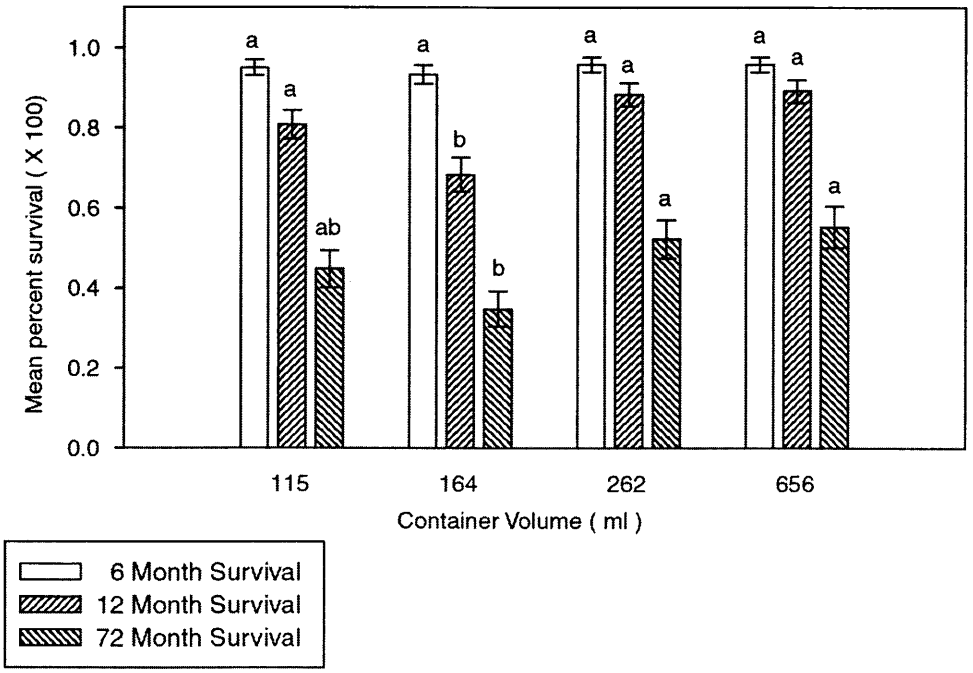


Figure 1. Mean survival by stock size for Arizona cypress planted in fall 1994 at Los Lunas. Means with same letter groupings within each measurement period did not differ significantly at $\alpha = 0.05$.

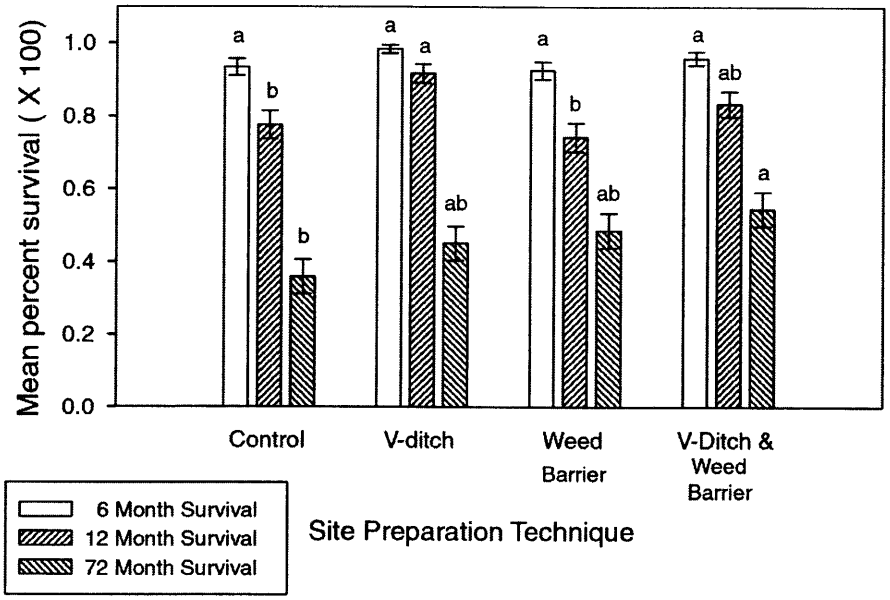


Figure 2. Mean survival by site preparation for Arizona cypress planted in Fall 1994 at Los Lunas. Means with same letter groupings did not differ significantly within each measurement period at $\alpha = 0.05$.

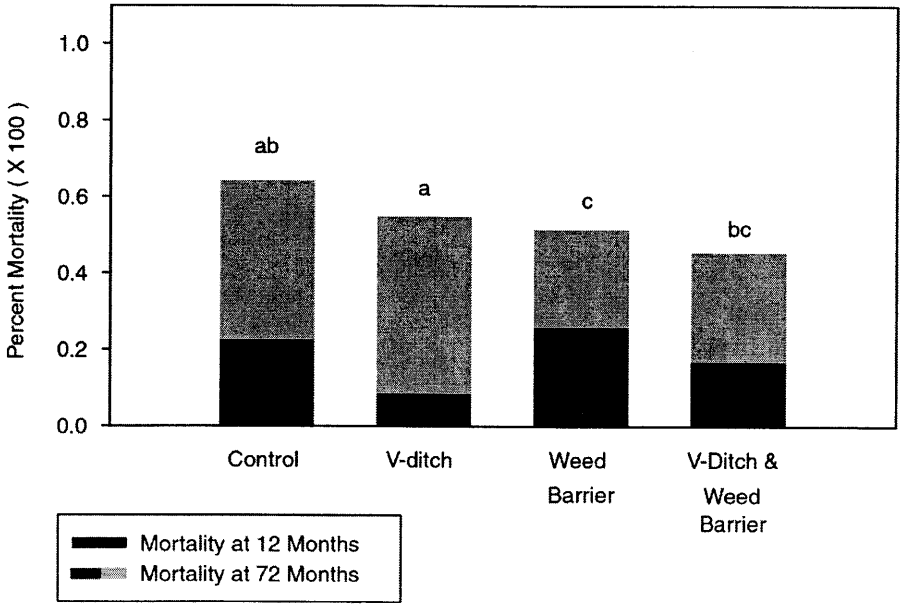


Figure 3. Proportion of 72-month mortality observed at 12 months by site preparation for the fall 1994 planting at Los Lunas. Mortality means for the 12 to 72 month growth period with same letter groupings did not differ significantly at $\alpha = 0.05$.

Table 1. Twelve-month mean survival by site preparation and stock size for Arizona cypress planted in fall 1994 at Los Lunas.

	Container Size (ml)							
	115		164		262		656	
	Survival[a] %	S.E.[b]	Survival %	S.E	Survival %	S.E	Survival %	S.E
Control	77cd	7.8	67de	8.7	77cd	7.8	90abc	5.57
V-Ditch	83abcd	6.9	97ab	3.3	90abc	5.6	97ab	3.33
Weed Barrier	77cd	7.8	53e	9.3	87abc	6.3	80bcd	7.43
V-Ditch / Weed Barrier	87abc	6.3	57de	9.2	100a	0.0	90abc	5.57

[a] Percentages followed by the same letter are not significantly different at $\alpha = 0.05$.
[b] S.E. = Standard Error.

Table 2. Seventy-two-month mean survival by site preparation and stock size for Arizona cypress planted in fall 1994 at Los Lunas.

	Container Size (ml)							
	115		164		262		656	
	Survival[a] %	S.E.[b]	Survival %	S.E	Survival %	S.E	Survival %	S.E
Control	40bcd	10.0	34cd	9.0	8e	5.5	62ab	10.1
V-Ditch	38cd	9.2	43bcd	9.2	58bc	10.3	43bcd	9.2
Weed Barrier	53bc	9.3	34cd	9.0	50bcd	9.3	60bc	11.2
V-Ditch / Weed Barrier	47bcd	9.3	27de	8.2	87a	6.3	60bc	11.2

[a] Percentages followed by the same letter are not significantly different at $\alpha = 0.05$.
[b] S.E. = Standard Error.

Survival rates for container size and site preparation treatment combinations varied considerably at both 12 and 72 months after planting. Seedlings produced in the 164 ml containers had consistently low survival in the two weed barrier treatments at both 12 months (Table 1), and 72 months (Table 2). At 72 months, survival of seedlings produced in the 656 ml and 115 ml containers was unaffected by site preparation treatment. In contrast, survival of seedlings produced in the 262 ml containers benefited as site preparation intensity increased. In this size category, seedling survival was 8% in the control and averaged 54% in the V-ditch and weed barrier treatments, but was 87% in the V-ditch/weed barrier combination treatment. Within the control group, seedlings produced in the largest containers (656 ml) had 60% survival after 72 months.

Size and Growth

Container size influenced shoot height in all measurement periods (Figure 4). At time of planting and six months thereafter, mean shoot heights for all container sizes were significantly different from one another. After 15 months, seedlings produced in the two largest container sizes had similar shoot heights, as did seedlings produced in the two smallest container sizes. At 72 months, seedlings produced in the 262 ml containers were taller than all others, while those produced in the largest (656 ml) and smallest (115 ml) containers had similar heights. Seedlings grown in 164 ml containers had the lowest mean

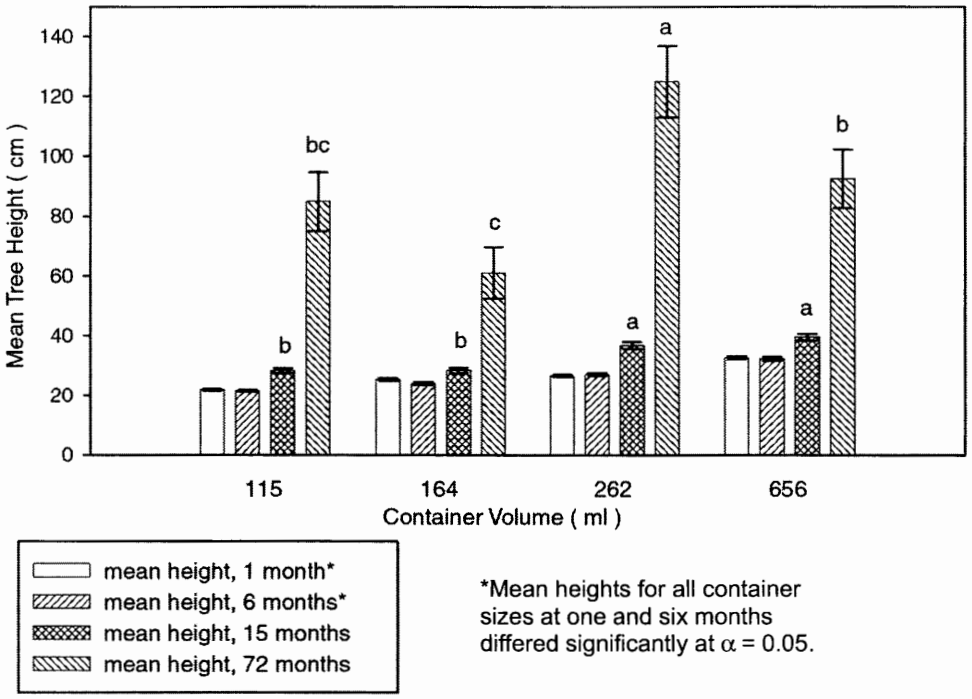


Figure 4. Mean height by stock size for Arizona cypress planted in fall 1994 at Los Lunas. Means within same letter groupings did not differ significantly within each year at $\alpha = 0.05$.

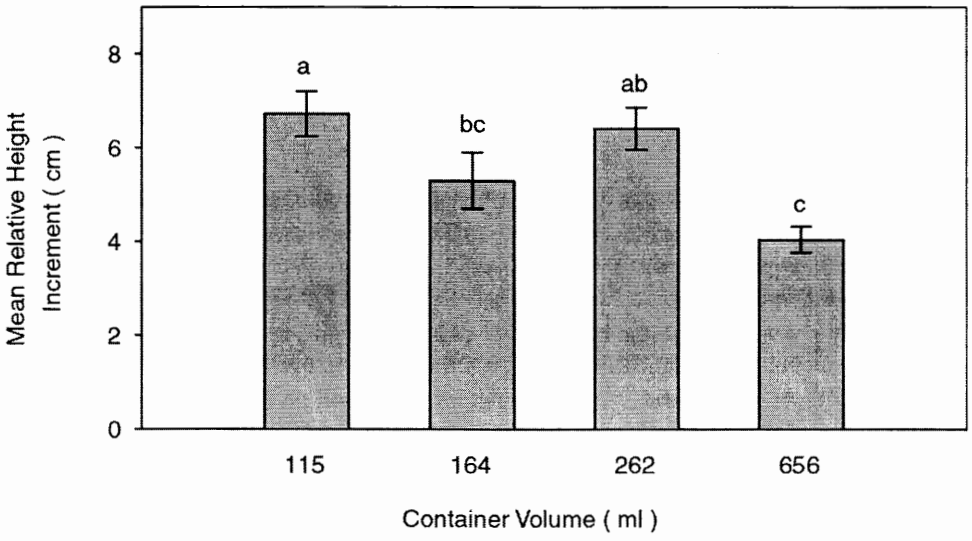


Figure 5. Mean relative height increment by stock size of Arizona cypress from time of planting to 72 months. Means within same letter grouping did not differ significantly within each year at $\alpha = 0.05$.

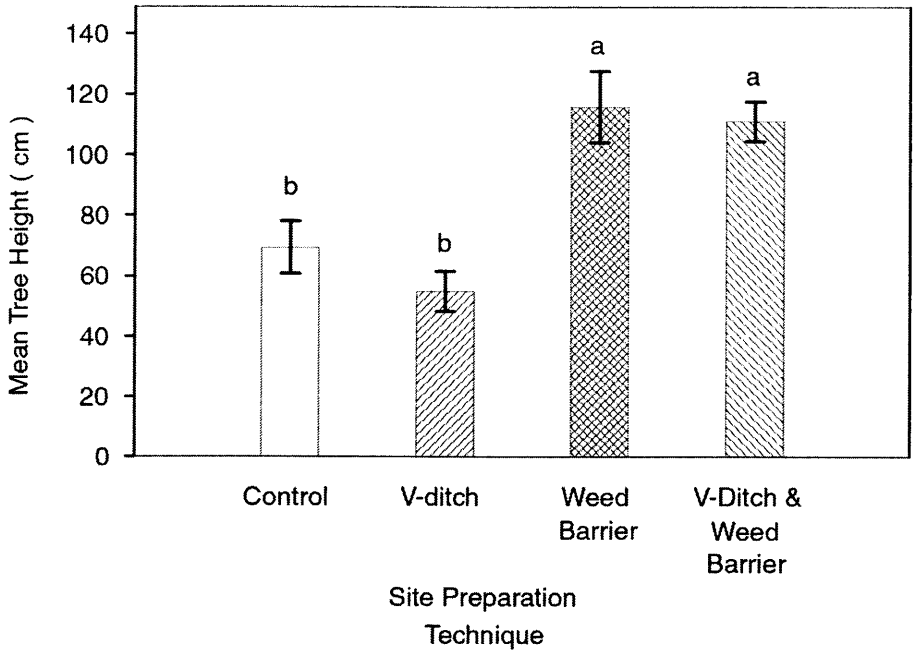


Figure 6. Mean height by site preparation technique for Arizona cypress 72 months after fall 1994 planting at Los Lunas. Means within same letter grouping did not differ significantly within each year at $\alpha = 0.05$.

height, but were not different than seedlings produced in the 115 ml containers.

Seventy-two month relative height increment was greatest for seedlings produced in the smallest containers and lowest for those produced in the largest containers (Figure 5). Seedlings produced in the two intermediate container sizes had relative height increments comparable to each other. Relative height increment was also similar between the 115 and 262 ml sizes, and the 164 and 656 ml sizes.

Site preparation treatments containing weed barrier increased 72 month seedling height relative to the control and V-ditch treatments (Figure 6). Mean seedling height for the two weed barrier treatments was 113 cm. In comparison, mean seedling height was 61 cm for seedlings growing in the control and V-ditch site preparation treatments. After 72 months, seedlings growing in the V-ditch treatment were small, but not significantly different from seedlings growing in the control treatment.

Trees in the weed barrier/V-ditch plots grown in 262 ml containers had a mean height of 193 cm after 72 months, which were substantially taller than trees growing in any other treatment combination (Table 3). The smallest mean height of 14.8 cm was found in trees from 262 ml containers grown in the untreated control plots. Height means within the weed barrier treatment were more similar across stock sizes than the other two site preparations.

Discussion

The most widely recommended site preparation technique for windbreak establishment in New Mexico is a V-ditch/weed barrier combination with drip irrigation (Brown and others 1992). While this protocol often results in survival rates of greater than 90% after one year (Harrington unpublished data), many sites lack an available or reliable water source for irrigation. Furthermore, drip irrigation systems can be cost prohibitive to install and/or maintain (Table 4).

While no overwhelming trends appeared in either site preparation treatment or stock size in this study, three notable outcomes were observed. First, in the absence of any site preparation, the largest stock size had the highest (60%) survival,

Table 3. Seventy-two-month mean height (cm) by site preparation and stock size for Arizona cypress planted in fall 1994 at Los Lunas.

	Container Size (ml)							
	115		164		262		656	
	Height[a]	S.E.[b]	Height	S.E	Height	S.E	Height	S.E
Control	64cdef	16.1	64cdef	15.7	15 f	10.0	107bcd	16.5
V-Ditch	52def	14.3	39f	10.4	80bcdef	16.1	55def	12.5
Weed Barrier	108bc	20.1	105bcd	25.0	122b	23.4	128b	27.5
V-Ditch / Weed Barrier	97bcde	20.5	52ef	16.7	194a	17.0	98bcde	20.2

[a] Heights followed by the same letter are not significantly different at $\alpha = 0.05$.
[b] S.E. = Standard Error.

Table 4. Estimated[1] costs of establishing windbreaks in New Mexico based on material costs of plant material and site preparation material. Costs are presented on a per 300m (1000 feet) of windbreak basis.

	Stock (Container) Size (ml)			
	115	164	262	656
Site Preparation				
Control	$70	$80	$130	$175
V-Ditch Alone	$70	$80	$130	$175
Weed Barrier Alone	$622	$632	$682	$727
Drip Alone	$202	$212	$262	$307
V-Ditch & Weed Barrier	$622	$632	$682	$727
Drip & Weed Barrier	$754	$764	$814	$859
V-Ditch, Weed Barrier, & Drip	$754	$764	$814	$859

[1] Estimates based on average of 2 to 3 quotes or catalog prices for the materials. In the case of seedling costs some were estimated, as they are not commercially available.

and almost 50% more than any other stock size evaluated. This may have been due to this plant material being better able to compete with existing vegetation. The larger root system volume and shoot size (Maiers 1997) associated with this stock type may have allowed them to compete with neighboring vegetation for site resources (in other words, soil moisture and light) more effectively.

In this study and those published elsewhere, one of two trends usually occur in seedling survival relative to stock size. Survival is either unaffected by stock size or larger stock has greater survival (Amidon and others 1981; Harrington and Maiers 1999; Harrington and Loveall unpublished data). A second notable and somewhat perplexing outcome in this study was the high mortality of stock produced in the 164 ml containers after the first growing season. Evaluation of stock attributes, including root volume, shoot height, root: shoot ratio found no unique features associated with this stock size (Maiers 1997). In

three subsequent spring plantings related to this study, the 164 ml stock type was consistently intermediate in survival when compared to seedlings produced in the other three container sizes (Maiers and Harrington 1999). A third notable outcome of this study was the exceptional performance of the 262 ml stock size in the combined V-ditch and weed barrier site preparation treatment. This treatment combination resulted in greatest survival (87%) along with the largest trees after 72 months (190 cm). This survival rate is considerably higher than the 72 month survival rate (36%) of spring planted Arizona cypress in New Mexico produced in the 262 ml container (Harrington and Loveall, unpublished data). As in this study, seedlings were only irrigated at time of planting.

An overall objective of site preparation is to improve seedling survival and growth by conserving site resources. In the arid and semi-arid southwest, water is often the most limiting site feature to seedling establishment. Inadequate site preparation in arid and semi-arid environments can result in planting failure (Fisher and Montano 1977; Nickerson 1990). Two techniques to increase moisture availability to plants were examined in this study. First, removing or eliminating competing vegetation and second, harvesting rainfall. The benefits of removing competing vegetation for improving seedling survival and early growth is well documented in the forestry literature. Often times the focus of these efforts is not to improve moisture availability, but to reduce light and nutrient competition. However, in the southwest reducing water loss to competing vegetation can increase transplant survival (Maiers and Harrington 1999). Improving moisture availability by rainfall harvesting has also been shown to be a highly effective technique to improving transplant survival (Al-Qurashi 1997; Maiers and Harrington 1999). Effects of site preparation were not evident in this study until after the first growing season where the two V-ditch treatments improved survival. The V-ditch treatment captures and stores rainfall for the seedlings to utilize. In addition, V-ditching appeared to provide some weed control throughout the first and some of the second growing season. After the second growing season, any weed control benefit from V-ditching was not readily apparent at this site or similarly treated sites elsewhere in New Mexico (Harrington pers. obs.).

A concern of using weed barriers or mulches in the southwest and southern Great Plains is the potential heating effects. Increased surface soil temperatures have been reported for synthetic soil mulches (Peacock and others 1990; Duncan and others 1992; Traux and Gagnon 1993). A study in Finland, found daily soil surface temperatures of up to 50 °C over a polypropylene mulch (Heiskanen and Raitio 1992). During this study, ambient temperatures reached or exceeded 30 °C. Conifer seedling exposures to 36 °C for two hours and 42 °C for one hour have been reported to be lethal (Roberts and Dong 1993). However, Al-Qurashi (1997) found no difference among control, weed barrier and V-ditch treatments on tree crown, and air and soil temperature within a windbreak study in the Middle Rio Grande Valley. In the same study, air temperature immediately above the weed barrier and control plots ranged from 32 °C to 38 °C for an 8-week period during the growing season. Benefits of the weed barrier site preparation treatments became apparent over time (72 month) in this study since survival and growth of seedlings improved. However, the benefits appeared to be stock size dependent.

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TREES ARE THE SOLUTION TO WASTEWATER TREATMENT FOR SMALL COMMUNITIES

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Abstract

The application of municipal wastewater to land for treatment and disposal, or "land farms," was one of the earliest forms of wastewater treatment technology. There has been renewed interest in using these systems in arid regions worldwide to supplement and reuse dwindling water resources. However, arid regions present complex challenges to the use of land application systems. Many arid regions (for example, Egypt and US/Mexico border) are located in areas that lack infrastructure support and cannot afford expensive treatment technologies. A slow-rate, land application system offers a low-cost treatment for these regions that can be integrated with advanced, integrated ponds, facultative lagoons or other inexpensive primary and secondary treatment technologies. Properly designed land application units provide environmentally safe wastewater treatment by removing pathogens, nutrients, and suspended solids. Additionally, the wastewater can be reused to create value-added benefits such as wetlands; bosques; trees crops for fuelwood, pulpwood, or lumber; and restoration of desert ecosystems. Critical to the design is the selection of tree species adapted to an arid environment, balancing seasonal plant water requirements with plant uptake of nitrogen and the nitrogen and salt loading from the wastewater. These factors must be carefully considered to assure system sustainability and minimize impacts to groundwater. Cases in Ojinaga, Chihuahua, Mexico; Las Cruces, New Mexico USA; and Ismailia Egypt will be discussed.

Key Words

Short rotation woody crops, wastewater reuse, land application, agroforestry, restoration

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Land application of wastewater is perhaps the oldest method for disposal and treatment of wastewaters. Early systems in England that received untreated wastewater were poorly understood and easily overloaded. Most of these systems were abandoned and replaced by other technologies such as trickling filters. In many areas of the world, wastewater reuse has been practiced using a combination of treatment technologies that achieve a high degree of treatment. Over the past twenty years, states in the western US have treated wastewater to tertiary treatment standards and then allowed the wastewater to be reused for irrigation or for recharge to groundwater aquifers. While this is an effective method of treatment and reuse, it is expensive and is rarely practiced in other regions of the world. Land application systems that utilize the land as a treatment unit and not just as a disposal area are gaining acceptance in many arid regions, because these systems are less expensive to construct and can be operated by personnel familiar with common irrigation systems.

With these systems, primary or secondary treated wastewater is applied to the land surface via furrow flood, micro-sprayer, or drip irrigation. Biological oxygen demand (BOD), total suspended solids (TSS), and fecal coliforms (FC) are partially removed in

the primary or secondary treatment steps. The land application unit removes additional BOD, TSS, and FC as well as nitrogen and phosphorus. The soil and plants act as filters that trap and treat, through various mechanisms, contaminants in the wastewater and allow the remaining wastewater (effluent) to drain through the soil profile (Watanabe 1997). The wastewater provides an effective source of nutrients that the tree roots assimilate. The net effect is a beneficial system allowing for both the effective remediation of wastes and the recycling of water, nutrients, and carbon via biomass production (Kerr and Sopper 1982; Bastian 1986). Not only is the waste problem managed, but also there is a potential for creating value-added products for economic development within the community from the resultant biomass. Several options including fiber farm plantations, bosque restoration, parks, and Christmas tree plantations have been proposed.

The basic approach to the design of land application systems is based on balancing the input of water and nitrogen (Figure 1) as outlined by Metcalf and Eddy Inc (1990) and WCPF (1989). The yearly wastewater application rate is based on the amount of total nitrogen (TN) allowed to enter the groundwater. Typically this is given in terms of the concentration of NO_3^--N in the wastewater reaching the ground water which can not exceed the drinking water standard of 10 mg NO_3^--N /L. The nitrogen uptake by the crop is related to evapotranspiration and crop yield using the evapotranspiration production function.

The water balance for this system with a selected tree species can be determined from locally derived data to determine the area required for the land application system. More importantly this information must incorporate plant nitrogen uptake rates and water use rates or crop coefficients to allow for proper balancing and ultimate system sizing. Finally, salt loading on the soil and its impact on tree survival and growth must also be considered. Many plants are less tolerant to salt during the establishment stage than in later stages, so alternative sources of water maybe required. Salt loading guidelines are provided in several resources such as WPCF (1990) and FAO (1992). Unfortunately, current design models do not take into account salt loading and interactions with soil EC. Systems we have dealt with have had salinities as high as 3,500 mg/L.

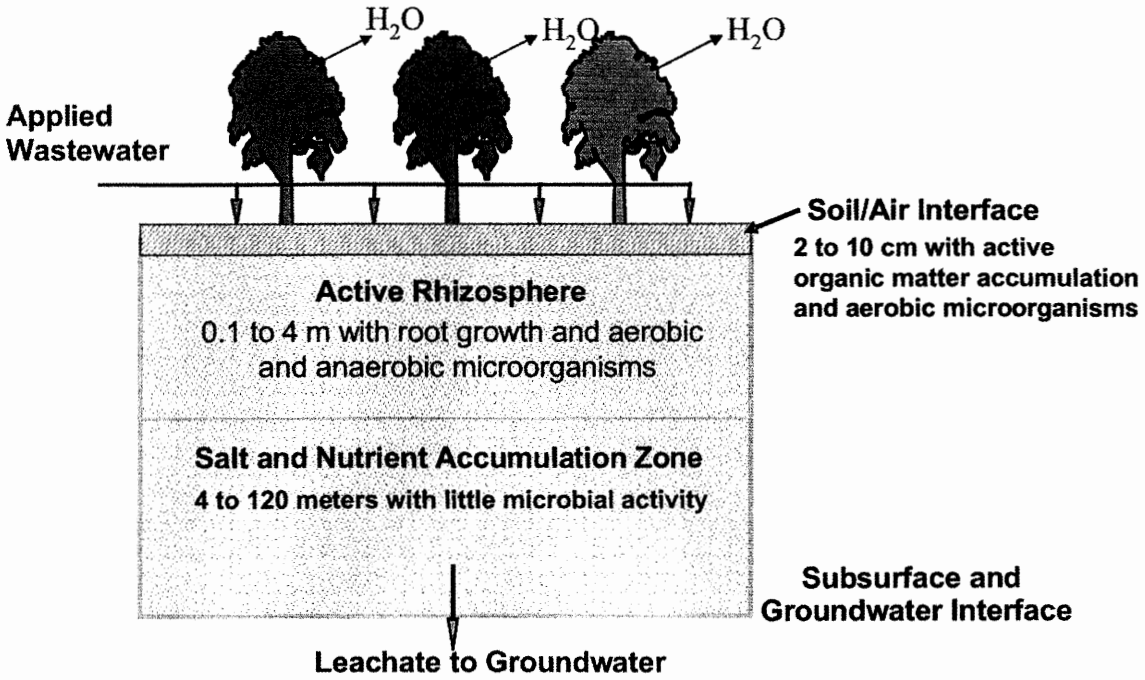


Figure 1. Mass flow schematic of the land application system for treating and reusing wastewater.

In the following sections, we provide summary information about three land application systems we have been involved with in arid regions.

Ojinaga, Chihuahua, Mexico

Ojinaga is located in the state of Chihuahua, Mexico, and situated at the confluence of the Río Grande (Río Bravo) and Río Conchos on the U.S.-Mexico border. The climate is arid, with an annual rainfall of less than 250mm, and temperatures ranging from -10°C to 50°C. The combined population of Ojinaga with its sister city, Presidio, Texas, is approximately 27,000 inhabitants. Ojinaga is demographically typical of smaller and intermediate-sized border communities. However, the population of Ojinaga has dropped from about 26,000 in 1980 to 23,600 people in 1995 because of emigration (USEPA 1996). Ojinaga is an agricultural community with 12,000 ha of irrigable farmland, but less than one-half of this land is currently producing crops such as alfalfa, corn, wheat, cotton, melons, onions, and pecans. One of the primary reasons that the land remains unfarmed is the landholdings average only five hectares each, making them too small to provide a sole source of income (Nuñez 1997). Consequently, many landowners have abandoned the land for employment in *maquiladoras* (twin plants) or in the US. Further, salty irrigation water has created unsuitable conditions for the production of many agronomic crops on some fields (Mexal 1997).

Historically, the municipal sewage has been piped directly into an anaerobic lagoon, which acts as a settling pond for separating the solids from the waste stream and providing some reduction in waste strength. The 1.5 ha (45,000 m^3) unlined treatment lagoon, which had served the Ojinaga community for over 30 years, was taken off-line in 1994 because it had filled with settled solids. A new 2 ha (60,000 m^3) anaerobic lagoon was constructed and put on-line in 1995, but it is expected to fill with collected solids within a few years. The existing wastewater treatment system is a single cell anaerobic lagoon receiving primarily municipal wastewater. Industries in the area, including bicycle assembly, slaughterhouse, and several cottage industries, appear to contribute little in the way of metals or toxic organics, but do contribute to hydraulic and organic loading of the wastewater. The slaughterhouse wastewater is intermittent, but high strength. The single-stage anaerobic lagoon is designed to remove biological oxygen demand (BOD), total suspended solids (TSS), and fecal coliform (FC) to some degree (Table 1). Wastewater from this system currently flows to pasture land and directly into the Río Grande, resulting in serious FC contamination of the river (Figure 2). The FC contamination presents a serious health hazard to down stream users on both sides of the border, including recreation users in the Big Bend National Park. In the future, the waste stream would flow to the land application unit for final treatment and disposal.

Table 1. System and wastewater characteristics of the three land application processes.

Parameter/Site	Ojinaga, Mexico	Las Cruces, USA	Ismailia, Egypt
Treatment Train	Screens/Primary-Anaerobic Lagoon	Screens/Primary-Aerated Lagoon	Screens/Grit/Primary-Aerated /Facultative Lagoon
Disinfection	No	No	No
Effluent BOD, mg/L	29-43	30	46
Effluent TSS, mg/L	15	30	23
Effluent TN, mg/L	14-37	45	45
Effluent TDS, mg/L	1,950-2,220	2,000-3,000	550
Flow, m^3/day	6,048	1,514	90,000
Land Application Area, ha	500	32	200-2000
Rainfall, mm/year	280	216	<2
PET, mm/year	2,450	2,220	2,341
Selected Crop(s)	Eucalyptus/ Hybrid Poplar	Creosote Bush, FourWing Saltbush, Mesquite	Italian Cypress, Stone Pine, African mahogany
Products	Wood Pulp	Habitat Creation	Wood Products and Fuel wood

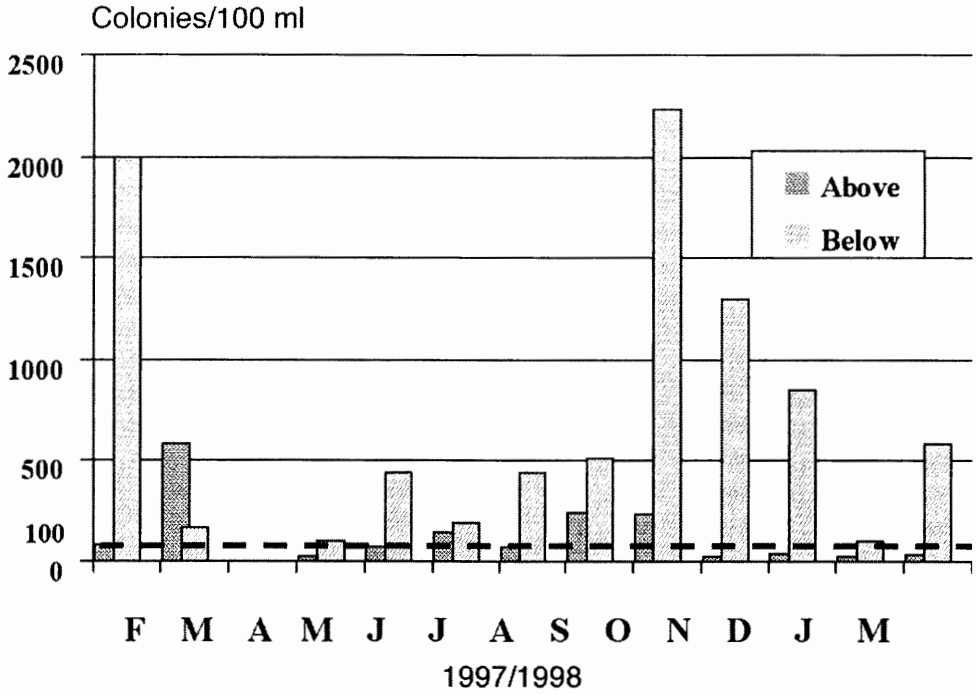


Figure 2. Fecal coliform contamination of the Rio Grande (# colonies/ 100 mL river water) above and below the discharge point of the primary treatment lagoon for the community of Ojinaga, Chihuahua, Mexico.

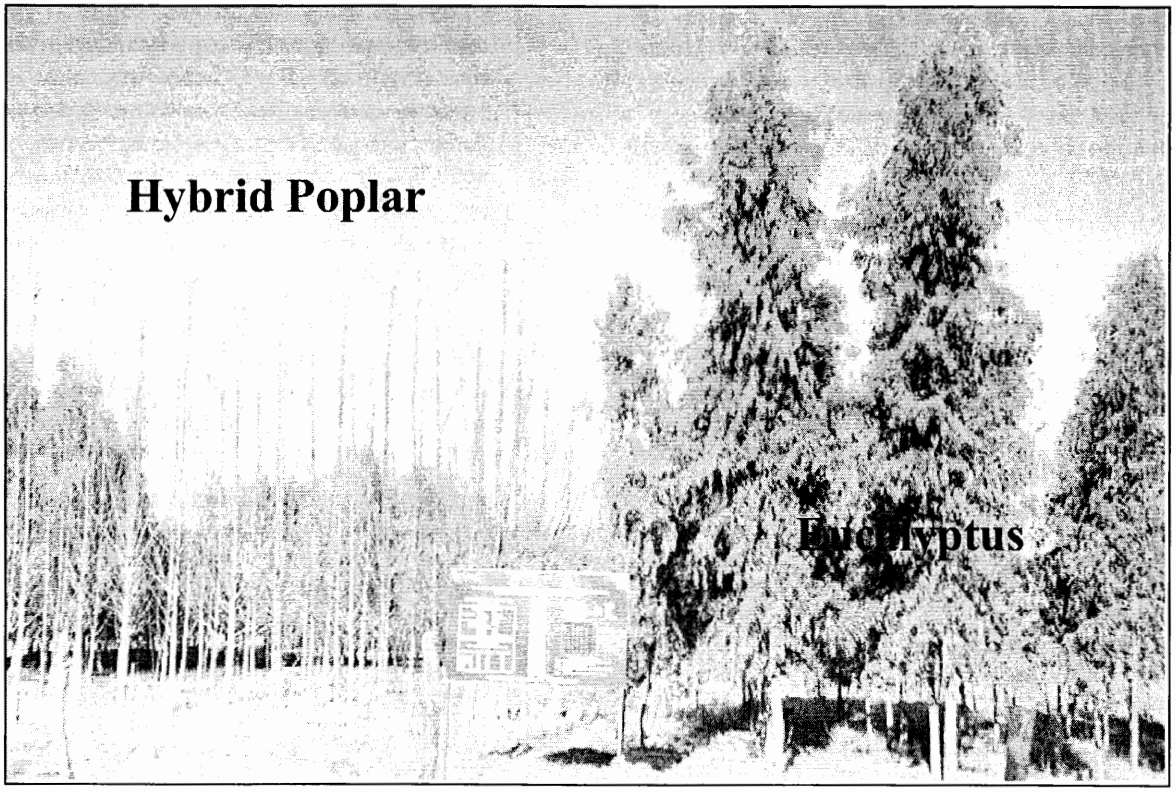


Figure 3. Three-year-old eucalyptus and hybrid poplar plantation under flood irrigation with treated wastewater in Ojinaga, Mexico.

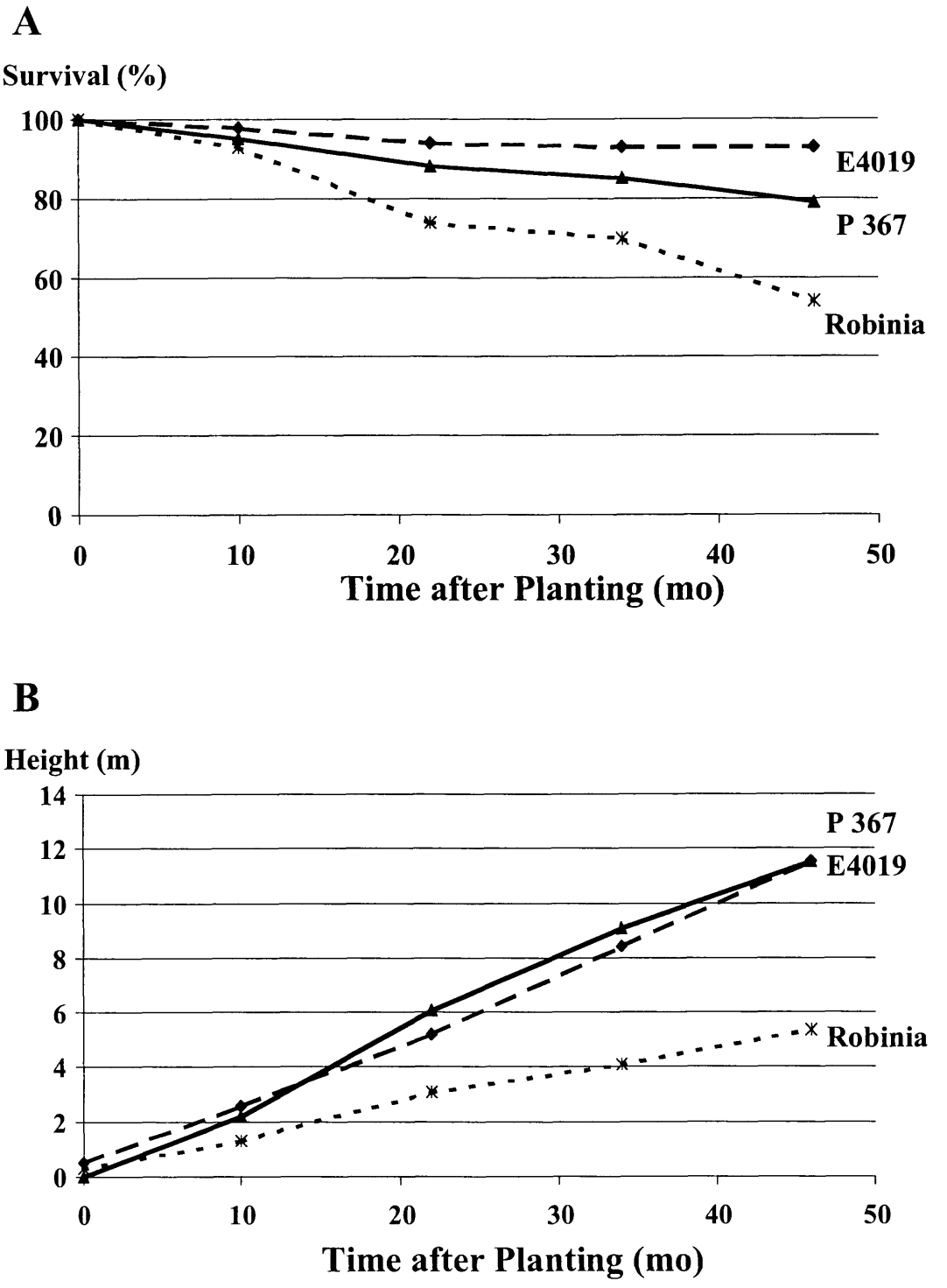


Figure 4. A) Survival (%) and B) height growth (m) of eucalyptus (clone E4019), hybrid poplar (clone P367), and Robinia pseudoacacia *after four growing seasons in Ojinaga, Mexico.*

A pilot land application site (~1.1 ha total area) was established in April 1997. *Eucalyptus* and *Robinia* seedlings, and *Populus* cuttings were transplanted at a 2m x 2m spacing (Figure 3). All of the plots were manually flood irrigated with water from an oxbow lake during the first growing season. The plots were flood irrigated with wastewater effluent and monitored for three additional years. Monitoring included wastewater effluent and groundwater quality characteristics, soils, and plant growth. Local PET and rainfall data was used to schedule irrigation rates.

After four years, there was minimal impact to groundwater with no increases in fecal coliform or nitrate and about a 10 percent increase in groundwater salinity. Tree growth results indicated that the optimal tree species were *Eucalyptus* and the 367 hybrid popular clones (Figure 4). The best clones survived well (>75% survival) and were over 11 m tall after four growing seasons. The growth rates achieved for these clones exceed expectations and may allow harvesting on a five-year rotation. This is one to four-years faster than other studies of similar species and will improve the overall economic impact of the process.

A full-scale system for the community could support a land application system of about 100 ha, and the capital costs for this system could be 30% less than conventional treatment systems while producing a highly saleable byproduct of wood chips for pulp. This endeavor could produce community-based jobs and have a positive cash flow for the operation and maintenance. Ojinaga has been involved in a master plan development process for the past three years for the development of a new treatment plant.

Las Cruces, New Mexico USA

The City of Las Cruces West Mesa Industrial Park has a stand-alone, centralized wastewater treatment plant. The industrial park was started in 1982, but the waste treatment facility was not completed until the summer of 2000. The goal of the system is to provide effective wastewater collection and treatment that will encourage the expansion of the Park, and also minimize the environmental impact of the Park on its surroundings by eliminating individual systems operated by Park tenants.

Aerated lagoons were selected as the best treatment technology because they are reliable with low capital and operations costs. The City of Las Cruces Pretreatment Ordinance requires industrial and commercial wastes be treated to reduce BOD to 250 mg/l and TSS to 200 mg/l. This pretreatment requirement also ensures that the facility will receive a fairly uniform influent quality. The proposed facility is expected to reduce these levels to produce an effluent quality of 30 mg/l BOD and 30 mg/l TSS (Table 1). This lagoon system typically produces low volumes of sludge that could be applied to the land application site as a source of additional fertilizer and organic matter.

One lift station transports the prefiltered, treated effluent to the land application site, which consists of 23 sprinkler zones, 1,600 sprinklers and 21,493 m of pipe covering 32 ha. Construction of the land application site used low impact methods to minimize disturbance to the native vegetation. The application of the effluent wastewater is operated on a rotational basis to allow infiltration of the wastewater and the nitrogen uptake by the native plants. The total capital costs for construction of the wastewater collection and treatment facilities was $2,700,000.

The goal of this system was to treat and dispose of wastewater in a cost-effective manner. A secondary benefit was the creation of improved desert habitat. Based on the water quality there was concern about accumulation of salts and the high concentration of nitrogen in the wastewater. Selecting native vegetation, primarily mesquite (*Prosopis* sp.) and creosote bush (*Larrea tridentata*) (Figure 5) allowed the system to accept high salt loadings while maintaining water application rates that would not have a negative impact on groundwater (75 m). Vegetation cover will be evaluated and soil will be monitored for the accumulation of salts beginning in 2002.

Ismailia, Egypt

The Ismailia Serrabium Wastewater Treatment Plant was built by Egypt and US AID in 1995 and is operated by the Suez Canal Authority. Ismailia has a population of about 500,000 and is located 9.4 km from treatment plant. The treatment plant design capacity is 90,000 m^3/d and the current flow is 80-85,000 m^3/d (Table 1).

Wastewater flow is divided to two parallel treatment branches with three lagoons

(aerated, facultative, and polishing lagoons) for each branch. The aerated lagoon has 20 aerators with 10 operating at any one time. The facultative lagoon also has 10 aerators that are used only as needed to increase dissolved oxygen. The polishing lagoon is 3.5 m deep to facilitate the removal of FC and *Ascaris* eggs. The total detention time of the system is 11 days, designed to reduce BOD, TSS, *Ascaris* eggs, and FC. *Ascaris* eggs and FC are considered the major health risk for using wastewater for reuse. The treatment plant does not have a disinfection unit nor does it provide tertiary treatment for nutrient removal. This treatment plant is a standard design for Egypt and several other similar systems are located in other areas of the country.

The land application facility is about 2 years old and uses a land area of about 200 ha with up to 2,000 ha available. The facility supports nursery and grow out operations. About 75 ha have been planted since July of 1998. Seedlings are planted on 3 m x 3 m spacing and drip irrigated with treated wastewater (Figure 6). The wastewater is filtered through an inline screen and then through several sand filters before it is delivered to the irrigation system. Ground water in the area is at about 8 m.

The nursery production capacity at Serrabium Forest is 100,000 trees per year. The trees are grown in polybags (12 x 15 cm), using a sand: clay: peat moss medium, and irrigated with wastewater. No additional fertilizer is applied during the nursery phase. Tree species produced are *P. pinea, P. halepensis, P. brutia* var. *eldarica, Khaya senegalensis, Cupressus sempervirens, Morus alba, Morus japonica*, and *Cassia* sp. The trees will be used for fuelwood, construction lumber, quality hardwood lumber, and silkworm production.



Figure 5. Landscape with mixed mesquite (Prosopis) *and creosote bush* (Larrea) *at the West Mesa Industrial Park land application site, Las Cruces, NM.*



Figure 6. Two-year-old Italian cypress plantation under drip irrigation with treated wastewater in Ismailia, Egypt

Initial observations illustrate the need to optimize this wastewater system. Individual trees are surrounded with 1 m wells for irrigation. Nevertheless, soil at the midpoint between trees (~4.2 m from the trunk of each tree) was saturated just below the soil surface. There was no soil layering or caliche development but attenuation of root development occurred at a soil depth of about 40 cm, presumably from hypoxia. This indicates over application of wastewater to the tree plots with no consideration of actual PET requirements. There is a high risk of groundwater contamination with this rate of application and a concentration of 45 mg N/L in the wastewater and depth to groundwater of about 8 m. Egypt is planning to expand this model to at least a dozen other cities and without proper guidelines all these sites are at risk.

Summary

These land application systems are in arid regions with low rainfall and high potential evapotranspiration. Thus, all water needs must be met by applied irrigation wastewater. This applied water must be balanced against the needs of the plant and salt and nitrogen loading to assure the development of a sustainable design. These conflicting interactions must be resolved through proper plant selection, site management, and irrigation scheduling. Proper safety precautions for personnel at these sites must be provided to minimize the risk of disease transmission. Finally the goals of the system in terms of the final product need to be incorporated into the process. Systems can be developed to produce revenue streams that can offset or some cases exceed operational costs. These systems can be publicly owned or private ventures, but infrastructure and community support must be developed well in advance and are essentially to the success of the project.

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NATIVE AMERICANS AND THEIR PLANTS: LINKING THE PAST WITH THE FUTURE

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Abstract

Seven nations of Native Americans in the US and Canada are using native plant species for restoration and to reintroduce populations of species of cultural significance due to habitat loss. The scope of their projects as well as the important environmental, cultural, and economic benefits resulting from their efforts are briefly described.

Key Words

Seedling, propagation, nursery, Blackfeet, Chippewa, Choctaw, Salish-Kootenai, Navajo, Ktunaxa Kinbasket, Mohawk

Nomenclature

(plants) ITIS (1998); (insects) Julien and Griffiths (1998)

In response to their rich ethnobotanical heritage, the need for restoration, cultural education, and providing employment opportunities, at least 7 native nations developed native plant nurseries for restoration projects in recent years. Integration of culture and ecology is a distinctive feature of their restoration projects. The fields of restoration and traditional plant knowledge and use are closely linked in many respects. Traditional harvesting coincides with replanting of rhizomes, seeds, bulbs, or offshoots in the pocket of soil where a plant was extracted. For example, the Salish-Kootenai replant the regenerative part of the crown of bitterroot (*Lewisia rediviva* Pursh [Portulacaceae]). When replanted in the hole where the root had been extracted, the crown (the caudex) grows and develops a new root system (DeSanto1993). The pocket of disturbance serves as a microsite for replanted propagules in the absence of competition the following year.

In other cases, rejuvenation of the population occurs in the case of those species dependant on some disturbance for increase. Rhizomes were dug in a particular way to stimulate additional rhizome development to grow into spur plants. This would ensure regrowth and sustainability. Collection of seeds, fruits, or branches involves the conservative practice of taking only a small quantity from any given individual or population. This is an ancient practice and continues today, not only for plant use but now also in the collection of seeds and cuttings for the purpose of restoration. Such cases demonstrate the understanding of, and respect for, biological systems and are inherent in the beliefs and relationship between indigenous people and their environment. Habitat loss of many culturally significant species is a concern expressed by many elders, tribal ethnobotanists, cultural advisors, and biologists. Undeniably linked is the need for conservation of these species and continuance of traditional plant knowledge, while addressing the immediate restoration. This approach has culminated in the development of native plant nurseries, restoration efforts, and cooperative programs between native nations and agencies.

Blackfeet Nation of Montana

The Blackfeet Reservation is over 600,000 ha (1.5 million ac) and encompasses a large expanse of northern short grass prairie with numerous wetlands, lakes, and rivers, as well as the interface with subalpine and alpine zones bordering Glacier National Park on the western boundary. The wide diversity of habitat and species illustrates both the diversity of plants of cultural significance to the Blackfeet and the range of restoration plants needed for upcoming projects.

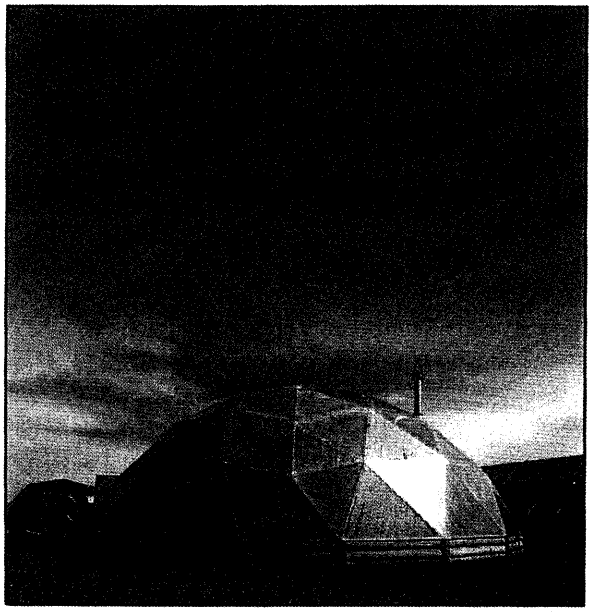


Figure 1. The Blackfeet's geodesic dome greenhouse was selected for its contemporary structural design which would withstand high winds, accumulate maximum solar gain for growing plants during winter months, and coincide with traditional values of the circle. (Terry McGrath Photography).

In 1998, a geodesic dome greenhouse (Figure 1) was constructed at the Blackfeet Community College in Browning, Montana. Wilbert Fish (greenhouse program manager and traditional Blackfeet herbalist) and his staff have successfully grown 53 native species for restoration and cultural-education purposes (Table 1). Emphasis on the cultural history and language is presented while species are under production (Figure 2), coinciding with the cultural education goals of the college and providing an opportunity to conduct horticultural trials with native species in a unique greenhouse environment.

Some traditional curative species being grown in the greenhouse include American licorice (*Glycyrrhiza lepidota* Pursh [Fabaceae]) and pale purple coneflower (*Echinacea pallida* (Nutt.) Nutt. [Asteraceae]). Key restoration species include

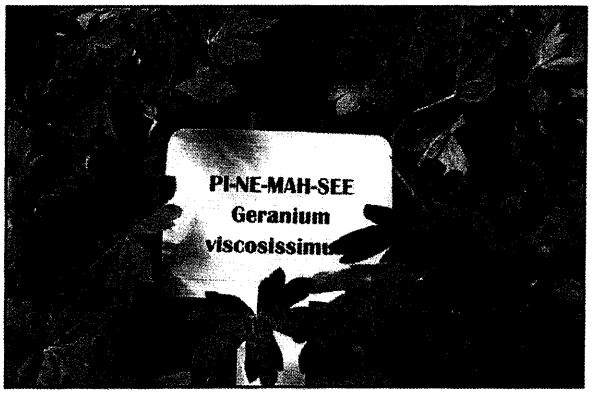


Figure 2. Pi-ne-mah-si or sticky geranium (Geranium viscossisimum) growing in the Blackfeet geodesic dome greenhouse (Terry McGrath Photography).

Table 1. Plants grown by the Blackfeet.

Scientific name	Family	Blackfeet name
Arctostaphylos uva-ursi (L.) Spreng.	Ericaceae	Ka-ka sin
Amelanchier alnifolia (Nutt.) Nutt. ex Roem.	Rosaceae	O-ko-nuk
Echinacea angustifolia var. *pallida* Nutt.	Asteraceae	Sik-doh-gee
Eriogonum umbellatum Torrey	Polygonaceae	OO- kak-see
Gaillardia aristata Pursh	Asteraceae	E-Nuk-En-Nee-Ga-Pono-Kooki
Geranium viscossisimum Fisch & Meyer ex Meyer	Geraniaceae	Pi-ne-mah-see
Glycyrrhiza lepidota (Nutt.) Pursh	Fabaceae	Mah-see-ye-poh-soh-goh-see
Hierochloe odorata (L.) Beauv.	Poaceae	Se-pat-semo
Mahonia repens (Lindl.) G. Don	Berberidaceae	Ot-squi-ei-na
Lewisia rediviva Pursh	Portulacaceae	Eks-ix-ix
Populus tremuloides Michx.	Salicaceae	As-si-tsix-im
Pinus contorta Dougl. ex Loud	Pinaceae	A-patakh-i

serviceberry (*Amelanchier alnifolia* (Nutt.) Nutt. ex M. Roemer [Rosaceae]) and chokecherry (*Prunus virginiana* L. [Rosaceae]) which are also important traditional food plants. Several species of sedges (*Carex* spp. [Cyperaceae]) have been grown for wetland and riparian zones on the reserve. Other species of ceremonial significance that have been grown include sweetgrass (*Hierochloe odorata* (L.) Beauv. [Poaceae]) and old man sage (*Artemisia ludoviciana* Nutt. [Asteraceae]).

In cooperation with Glacier National Park, the greenhouse is used to produce plants for campground restoration involving students from the Browning School District. Students collect seeds and assist in propagation and out-planting. Mr Fish and his staff are currently growing culturally significant species for the Piegan Institute, which operates 2 total immersion Blackfeet Language schools and desires a cultural-botanical park for each school.

Ojibwa (Chippewa) of Minnesota

The Chippewa (Objibwa) of Minnesota consists of 7 Bands: Bois Forte, Fond du Lac, Grand Portage, Leech Lake, Mille Lacs, White Earth, and Red Lake. Wild rice (*Zizania palustris* L. [Poaceae]) management on reserve lakes is a priority in order to enhance and restore wild rice production and to increase nesting habitat for migratory waterfowl.

Just one of several restoration projects, the Fond-du-Lac Band near Duluth, Minnesota, are inventorying populations of wild rice using global positioning system (GPS) mapping techniques in conjunction with restoring 300 ha (750 ac) of formerly channelized, dammed, or altered wetlands and lakes to their former capacity with wild rice. David Wise, USDA Natural Resource Conservation Service (NRCS) tribal liaison is coordinating the projects.

The White Earth Band of the Ojibwa are also involved in wetland restoration in Minnesota. Restoration of 3.5 km (2.2 miles) of the Wild Rice River, located south of Lower Rice Lake, came about due to the construction of a new bridge. As part of the construction, Minnesota Department of Transportation restored flow to a part of the river that for decades was diverted into a ditch parallel to the highway. The project restores hundreds of hectares of floodplain wetland and provides deep-water habitat for northern pike and other fish. The restored wetland will help moderate water-level fluctuations in Lower Rice Lake, thus reducing damage to young wild rice from high water in early summer (MDNR 1999). The project benefits native people, wild rice, fish, and wetland wildlife which have been waiting more than 50 y for this river's recovery.



Figure 3. Choctaw members planting switch grass rhizomes (Photo by Tim Oakes).

Choctaw Tribe of Mississippi

The Choctaw live within a species and habitat rich area of Mississippi. The forest is an oak-pine-hickory association with a diverse sub-canopy of several other species of oak, gum (*Liquidambar styraciflua* L. [Hammelidaceae]), and tall shrubs. Herb cover may reach 20% in forests that have been burned. In moist locations, switch cane may form dense canebrakes. Species richness is also evident in the many types of wetlands common in this area.

The Mississippi Band of the Choctaw are dedicated to preservation of their cultural way of life and have recognized that plants of cultural significance are increasingly being threatened due to habitat loss. A cooperative effort between the Choctaw tribal council, Agriculture and Rural Development office, and NRCS has resulted in several innovative projects to address this problem. Three projects are addressed below.

Choctaw elders expressed concern about limited populations of switch cane (*Arundinaria gigantea* ssp. *tecta* (Walt) McClure [Poaceae]) on tribal lands. Switch cane is the largest native grass in North America, growing 2 to 8 m (6.5 to 26 ft) tall with stems up to 2 cm (1 in) in diameter. Cane fiber is used in Choctaw basketry, recognized worldwide as some of the most exquisite basketry, and is an important source of income for tribal basket makers. Chief Phillip Martin and the tribal council requested a collaborative project between the

Choctaw and NRCS to transplant sections of cane back into suitable habitat on the reservation, and also to introduce it in areas were it would be easily accessible by basket makers and elders (Figure 3). Tim Oakes, NRCS liaison, is investigating vegetative propagation of cane for these purposes and for slope and stream bank stabilization. Elders provided information on historic locations, which are being mapped by GPS.

A 7 ha (18 ac) section adjacent to the Pearl River will be restored with forest tree seedlings and cane. A vocational tribal greenhouse and nursery facility produces bareroot Nutall's oak (*Quercus texana* auct.non Buckl. [Fagaceae]) and hickory (*Carya alba* (L.) Nutt. ex Ell [Juglandaceae]) for restoration, and for wildlife food and cover values. The greenhouse employs tribal members who collect seeds, grow, and maintain tree seedlings. Trees are also available to locals for backyard habitat enhancement on private land. Both species are of cultural significance to the Choctaw as traditional food sources (Moerman 1998). The traditional Choctaw stick ball game (Ishtohboli) requires a pair of hickory stickball sticks. Preservation of existing wetlands and enhancement and installment of additional wetlands on tribal lands is a priority of the Choctaw and they have been recognized for their initiative of tribal wetland projects. The Choctaw and Army Corps of Engineers recently agreed to restore and enhance tribal wetlands. Wetland protection and restoration by the Choctaw have set an example in the southeastern US.

Another cooperative project was development of the Wolf Creek Nature Trail, located at the Pearl River Community. The Choctaw intended to create a demonstration area focusing on environmental concerns, such as restoration, enhancement, and creation of wetlands and habitat for wildlife. Information about plants encountered along the trails is provided in both Choctaw and English, providing environmental education to school groups and visitors, as well as an opportunity for youth to learn from elders and examine plants of cultural significance.

Confederated Salish-Kootenai Tribes of Montana

The Salish- Kootenai reservation ranges from 900 to 3000 m in elevation and includes shortgrass prairie, the Flathead River drainage, wetlands, and the forested west slope of the Mission Mountain Range on the eastern boundary.

The Salish-Kootenai constructed a nursery at their Salish-Kootenai College in Pablo, Montana, to provide plants for restoration of riparian zones in the Flathead River and its tributaries, and upcoming federal highway projects on the Flathead Reservation. The nursery is part of a program combining restoration, control of exotic weeds, and college curriculum. Instrumental in the program are JoAnne Bigcrane, ethnobotanist and liason between tribal elders, Virgil Dupuis, restoration project manager, Pat Hurley, biology instructor at the College, Dawn Thomas-Swaney, nursery manager, and Joyce Lapp, restoration biologist at Glacier National Park.

Planning and preparation for this long term program included looking for culturally significant species in proposed restoration areas and searching historical records to see if culturally significant species originally occurred on potential restoration sites. Historical records provide a means of accessing the impact of habitat loss and exotic invasion on populations. The Elders participation was invited to oversee the selection of native plants for restoration projects, and suggest how appropriate care and handling was to be given to the plant species and materials. The nursery includes 2 greenhouses, a shadehouse, and 4 outdoor mistbeds for vegetative propagation. Student interns from the College assist with seed collection and propagation and production of plants. The College's restoration ecology curricula prepares students for local employment on the project, as well as other opportunities in restoration and horticulture, as they take an active role in management of their land.

As part of the program, the Salish-Kootenai plan to involve tribal members in contract production of bareroot woody material and establishment of seed grass orchards for other restoration projects.

Of the 80 ha (200 ac) of proposed riparian restoration, the Salish-Kootenai are starting with conversion of a 24 ha (48 ac) pasture on a floodplain along the Flathead River (Figure 4). Their objectives are to reestablish the historic floodplain by reintroducing willow (*Salix* spp. [Salicaceae] and Black cottonwood (*Populus trichocarpa* Torr. & Gray ex Hook (Salicaceae) to the shoreline, enlarging and rehabilitating the existing wetlands with sedges, rushes [*Juncus* spp. [Juncaceae] , and native shrubs and to reestablish the adjacent ponderosa pine

(*Pinus ponderosa* Dougl. [Pinaceae]) and Rocky Mountain juniper (*Juniperus scopulorum* Sarg. [Cupressaceae]) forests. Existing populations of the culturally significant species American plum (*Prunus americanus* Marsh. [Rosaceae]) will be revitalized and augmented as well.



Figure 4. Dawn Thomas-Swaney collecting hardwood willow cuttings along the Flathead River in Montana (Photo by Joyce Lapp).

Plants for this project include red-oiser dogwood (*Cornus sericea* L. [Cornaceae]), woods rose (*Rosa woodsii* Lindl. [Rosaceae]), willow (*Salix* spp.), thin leaf alder (*Alnus incana* (L.) Moench [Betulaceae]) and snowberry (*Symphoricarpos albus* (L.) Blake [Caprifoliaceae]). Rooted cuttings of Bebb's willow (*Salix bebbiana* Sarg.[Salicaceae]), and black cottonwood are being grown for a 10 ha (20 ac) restoration project along the Jocko River.

The Reservation has an extensive exotic weed problem. Success of restoration projects is contingent on control of weeds. JoAnne Bigcrane works closely with the Reservation's Weed Division to examine the impact of herbicides on native species. Linda Weaselhead manages an insectary where sulphur knapweed moth (*Agapeta zoegana* L. [Lepidoptera:Tortricidae]) and knapweed root weevil (*Cyphocleonus achates* Führ. [Coleoptera:Curculionidae]) are grown for biological control of spotted knapweed (*Centaurea maculosa* L. [Asteraceae]).

The Salish-Kootenai have, through careful planning and development, a restoration policy and protocol with tribal elders, conservation and protection of culturally significant plants, development of a nursery, exotic plant management, and a curriculum for the field of restoration aimed at providing employment, a program others should emulate.

Ktunaxa Kinbasket of British Columbia

Ktunaxa Kinbasket lands are very diverse in vegetation, ranging from the dry, ponderosa pine–bunchgrass (*Elymus spicatus* (Pursh) Gould [Poaceae]) zone to the coastal western hemlock (*Tsuga heterophylla* (Raf.) Sarg. [Pinaceae]) zone and in some places, subalpine and alpine zones.

The need for restoration of hydro-electrical right-of- way on Ktunaxa Kinbasket land prompted development of an on site indigenous plant nursery on the north end of the St. Mary's Reserve near Cranbrook, British Columbia. Michael Keefer is ethnobotanist and Pete McCoy serves as cultural advisor and liaison between elders and the ethnobotany program. Keefer and McCoy have collected seeds for several projects (Figure 5). One major contract with Columbia Power Corporation involves growing huckleberry (*Vaccinium membranaeceum* Dougl. ex Hook [Ericaceae]), ninebark (*Physocarpos malvaceus* (Greene) Kuntze [Rosaceae]), chokecherry, snowbrush (*Ceanothus velutinus* Dougl. [Rhamnaceae]), and red stem ceanothus (*Ceanothus sanguineus* Pursh [Rhamnaceae]) from seeds. Snowberry and willow will be



Figure 5. Michael Keefer (left) and Pete McCoy (right) collecting seeds (Photo by Bev Hills).

vegetatively propagated. With this great range of diversity and the need for restoration in many areas, Keefer sees the challenge of growing many additional species. Experimentation and refining the growth requirements for diverse species under greenhouse conditions is necessary for future projects.

A youth ranch, in conjunction with the nursery, is under development and will involve horticulture apprenticeships and employment for youth. The nursery and ranch provide jobs and skills and ensure use of site specific nursery stock.

Mohawk Nation of New York

The St Regis Mohawk Reservation includes 5666 ha (14,000 ac) in New York and additional land across the border in Canada. The vegetation is a mosaic of eastern hardwood deciduous and coniferous forests bordering the Hudson River. In cooperation with NRCS, the Mohawk are developing a wetland enhancement project involving the Akwesasnie Freedom School. Students from the school will be involved in seed collection of wetland species that are also of cultural significance, growing and planting plugs, as well as gaining knowledge of the traditional uses of these species from participating elders. Plugs will be grown or sections transplanted from adjacent wetlands and planted in the wetland zone of 3 newly constructed ponds. Also, members of a tribal environmental task force collect and transplant viable rhizome sections of sweetgrass for restoration of this important component in traditional basketry (Figure 6).

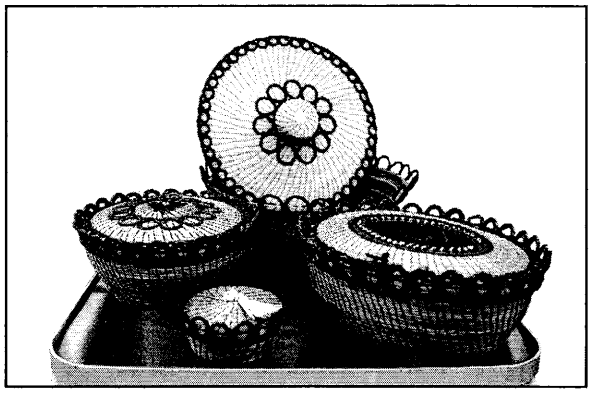


Figure 6. Sweetgrass baskets (Courtesy of Rose Lake Plant Materials Program).

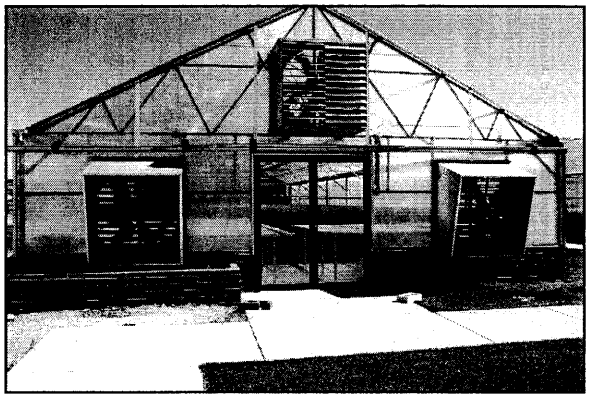


Figure 7. Production greenhouse operated by the Navajo Nation (Photo by Amanullah K Arbab).

Navajo Nation of Arizona and New Mexico

The Navajo Nation is the largest reservation (6500 km^2 [1.6 million ac])) in the US. Piñon-juniper woodlands (*Pinus edulis* Engelm. [Pinaceae] – *Juniperus* spp. [Cupressaceae]) are an important vegetation component of the reservation and contain many species of cultural significance to the Navajo people. The tribal nursery is located in Fort Defiance, Arizona, and consists of several greenhouses, a lathhouse, seed extractory, and warehouse. Recently, the nursery has also successfully propagated 36 additional native species (130,000 per y) for restoration projects on the reservation, species that are culturally significant and important for wildlife. (Table 2). The nursery also produces 1,000,000 forest tree seedlings per year (Figure 7).

The nursery employees 9 to 27 tribal members and works with graduate students from University of New Mexico. Mr Amanullah K. Arbab manages the nursery and has developed a native plant botanical garden at the nursery. The garden serves as a learning tool for young Navajo school children that visit the nursery to learn first hand the cultural, ceremonial, and medicinal uses of native plants and principles of restoration and ecosystem mangement.

The Navajo face many challenges for restoration on the reservation, and are studying microflora associated with reestablishment of native plants following coal mine reclamation.

Table 2. Plants grown by the Navajo.

Skunk bush sumac	Anacardiaceae	*Rhus trilobata* Nutt.
Smooth sumac	Anacardiaceae	*Rhus glabra* L.
Big sagebrush	Asteraceae	*Artemisia tridentata* Nutt.
Old man sage	Asteraceae	*Artemisia ludoviciana* Nutt.
Fringed sagewort	Asteraceae	*Artemisia frigida* Willd
Black sagebrush	Asteraceae	*Artemisia nova* A. Nels
Rubber rabbitbrush	Asteraceae	*Chrysothamnus nauseousus* (Pallas ex Pursh) Britt.
One seed juniper	Cupressaceae	*Juniperus monosperma* (Engelm.) Sarg.
Utah juniper	Cupressaceae	*Juniperus osteosperma* (Torr.) Little
Rocky Mountain juniper	Cupressaceae	*Juniperus scopulorum* Sarg.
Gambel's oak	Fagaceae	*Quercus gambelii* Nutt.
Curl leaf mountain mahogany	Rosaceae	*Cercocarpus ledifolius* Nutt.
Birch leaf mountain mahogany	Rosaceae	*Cercocarpus montanus* Raf
Cliff rose	Rosaceae	*Purshia mexicana* (D.Donn) Henrick.
Apache plume	Rosaceae	*Fallugia paradoxa* (D.Donn.) Endl
Utah serviceberry	Rosaceae	*Amelanchier utahensis* Koehne
Chokecherry	Rosaceae	*Prunus virginiana* L.
Woods rose	Rosaceae	*Rosa woodsii* Lindl.
Golden currant	Rosaceae	*Ribes aureum* Pursh
Coyote willow	Salicaceae	*Salix exigua* Nutt.
Scouler willow	Salicaceae	*Salix scouleriana* Barratt
Cottonwood	Salicaceae	*Populus angustifolia* James

Summary

Native American restoration projects are addressing the need for providing skills and opportunities for tribal members and in restoring landscapes for future generations. The vast botanical knowledge of the indigenous people was accumulated through intensive observation of the environment in which they lived for thousands of years. Traditional indigenous resource management engaged restoration with harvest, inferring that continuance of culture is intertwined with the health of the ecosystem.

Today, restoration on indigenous lands is a concept whose time has come in many areas of North America. The challenges of growing native species and researching methodology for restoration, while integrating traditional beliefs and management practices is of great importance as many nations and agencies work to restore impacted landscapes. These challenges can be approached successfully from the traditional cultural perspective.

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Naturally Occurring Plants Used on the Hopi Indian Reservation for Medicine and Food

Theodora Homewytewa

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Homewytewa, T. 2002. Naturally Occurring Plants Used on the Hopi Indian Reservation for Medicine and Food. In: Dumroese, R.K.; Riley, L.E.; Landis, T.D., technical coordinators. National Proceedings: Forest and Conservation Nursery Associations—1999, 2000, and 2001. Proceedings RMRS-P-24. Ogden, UT: USDA Forest Service, Rocky Mountain Research Station: 343-344. Available at: http://www.fcnanet.org/proceedings/2001/homewytewa.pdf

Key Words

Native plants, medicinal plants

Good morning. My name is Theodora Homewytewa. I'm from the Hopi tribe. And I feel naked. [laughter] I have no slides, nothing to show you, except for what I have here from my heart. That's how I am when I do my work.

My tribe is here. I'm very very glad to see Max here this morning. (Max Taylor, Hopi Tribal Range Management) He's from the Hopi tribe. I thought I was going to be lost but I feel OK now. [laughter]

My work is working with people. I am who they call a medicine woman. I gather my herbs and I work with plant life. I don't plant it and I'm not there helping it grow. So this conference has been very interesting for me. I wish I could plant some plants that I need for the people.

But my way of doing it is, I collect my plants from the wild. I don't go out and collect a whole abundance of a certain plant. I go out there to see where it is and if what I need is there. Then I pick only what I need.

People come to me for help, and I do work on them for various reasons. There are different kinds of plant-herbs that I use, accompanied by a lot of prayer—always a lot of prayer. The Native American people here know what I am talking about. And when I am going to work on a person, I already know through prayer what she is going to need. Someone comes to me for a certain ailment and I know what I am going to use. But I have to be certain that I know what I am doing so I don't double the dose of what Western medicines this person may already be using.

All the medicinal products that I use are pure. I don't have any chemicals or stuff that I mix with my things. Right now I know that there are a lot of plant remedies that are being used in Western medicine, but they are mixed with other things.

I'm very glad that other tribes here are doing what they are doing right now, because I see that they are replanting. A person like myself that uses plant life, I gather the seeds of a plant that is mature, and other times I get the leaves. Sometimes I take the root. But never everything. In this way there is always something left that can take the place of what I used.

I was taught by my uncle, who was a medicine person before me, that when picking my medicinal products anywhere on the reservation, that the location would be kept to myself, that this would be a secret. Because if I told anybody, especially the Anglos, then I would wake up tomorrow and these plants would be gone. He meant that people are always looking out for and trying different kinds of remedies. So we are very traditionally aware of things that are going on so that hopefully it's done by trained people.

When I talk at conferences, I do it with feedback, so I am not the only person up here talking. We're all here to learn. I'd like you to do the same. So if you have questions, please feel free to interrupt.

There are many herbal plants out there. I brought some with me today. They are on display outside. Some are used for medicine as well as for food. It depends on what you bring home or collect. We go out traditionally at certain times of the month or the year. If you grew up eating these things,

then you know that certain days are going to be the days when you go out and collect that plant.

An example is a plant that you call, I think, petite marigold (Du-ets-ma, Lemonscent, *Pectis angustifolia* Torr.). When we have an abundance of rain, we all know where in certain parts of this valley or that hillside it's going to be. It's used for spice. It's very precious for Hopi people. We go pick it and dry it and store it. We add it to salt water and then cook it with our pea pods, or else when we have a roast we put it on there as a seasoning. But, again, if you have a migraine headache, then I am going to boil it and give it to you as a tea to clear your head.

We have certain types of mints that grow wild (Mu-Eng-Dosh-Ha-Vu, *Poliomintha incana* Torr.). We don't plant them; they are wild. There are certain types that I go and pick for medicinal products. For instance, if someone came to me for sinus problems and they have asthma and need to be cleared, then I would go out and collect this plant and would make a tea. And it depends on what kind of mint it is. If it was peppermint, then you can boil the tea stronger. Make sure that someone else does the picking for you if you have asthma or the pollen is going to get you before you get yourself well. [laughter]

The mint is like Vic's, it's got vapor. So the mint, when you boil it, has got these vapors, and your sinuses are really clogged, and you drink this and it hits it like that [pointing to sinuses]. So that helps.

I've got medicines for diabetes. I've had people that were really, really bad with sugar diabetes whose sugar levels have come down from my medicines. The doctors out there that I do work with, we come together and compromise on things. I'm telling one doctor, "OK, this patient of mine is here to see me because of this reason, and I am going to administer my herbal medicines and I have certain types and this is what I am going to use." And then he says, "but they are already taking this." I fight all the time because they don't always believe the things that I say. And then we start getting rid of his stuff, and he says, but this is what is keeping this person alive, and I say how can you really be sure?

This medicine called Valium is one of the things that I really frown upon. I won't give that to my patients, and western doctors are administering that and they're happy because this person over here is now forever over here [indicating floating up with her hands, laughter]. And so I'll take this away and give dandelion (*Taraxacum officinale*). When they are just coming up fresh, they are still tender, so you pick them...well, pray first. Your prayer is always there, that what I am taking is going to help this person.

I've said this before. Many of you have lawns out there, and you just go and mow them and you don't care. You just pull those weeds out. To the Anglo people that's not food. But the dandelion flowers are really precious to me, so I save them and I dry them, and this is what I would use to give to a person to calm them down. It's got a natural ingredient that calms a person down. So if you are really very tired from today, go outside on the lawn and find some [laughter]. And the landscaper, he will be glad, too, because he wants to get rid of it. These are the things that are really common here. But you don't make use of them; you see them as weeds.

We use creosote bush (*Larrea tridentata* (Sessé & Moc. ex DC.) Coville). We call it chaparral. It's not on the reservation. It's only found in warmer arid areas. What I do is I boil mine. I boil it three times or it will be too strong. But I don't get rid of the first two boils. I save the water for other uses. The first water I save because sometime that day someone is going to come to me with athletes foot or psoriasis. And you soak your feet or wash your arms or whatever you need and it takes care of that. The second boil is not as strong, and I would add red clover and it can be used as a tea for cleansing the system. The third boil I give as a tea to strengthen the blood.

I learned these things over many years, and from my Uncle. And there are ritual songs that I know that help to teach these things. And the stuff that is edible are common things. Stuff the whole tribe knows of. The salt bushes (Eu-Nah-Do-Ki, *Atriplex* spp.), the plant with the purple flowers that we eat like spinach when it's young (Du-ME, *Cleome serrulata* Pursh, Rocky Mt. bee-plant), roots that are edible at certain times of the year. I wish I knew how to grow these things just outside my door. But I am learning from you [laughter]. So this is how I do my work.

THE 'AHAKHAV NATIVE PLANT NURSERY ON THE COLORADO RIVER INDIAN RESERVATION: GROWING TREES AND SHRUBS FOR SOUTHWEST RESTORATION

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Abstract

The Colorado River Indian Reservation is located in southwestern Arizona on the California/Arizona border. On the reservation is the 'Ahakhav Tribal Preserve, located on the banks of the Lower Colorado River. On the preserve is the 'Ahakhav Native Plant Nursery, specializing in plants used for southwest riparian restoration. The nursery primarily grows native mesquite, cottonwood and willow. Due to increased competition and minimal tribal support, the nursery is at a critical turning point.

Key Words

Colorado River Indian Tribes (CRIT), *Populus fremontii*, *Prosopis glandulosa*, *Prosopis pubescens*, *Salix exigua*, *Salix gooddingii*, southwest riparian restoration, Tamarix

THE RESERVATION

The Colorado River Indian Reservation (CRIR) was established on March 3, 1865. The reservation is on the Arizona/California border on the banks of the Lower Colorado River and is approximately 375,000 acres. It 3,500 members come from four Indian nations, the Mohave (having the most members), Chemehuevi, Navajo and Hopi.

The Mohave and Chemehuevi are native to the area. The Mohave were traditionally more agricultural, utilizing fish from the river and mesquite beans as a food source. The Chemehuevi were more nomadic. The BIA, in an effort to get more of the reservation under cultivation, offered to relocate Hopi and Navajo members to the CRIR with the promise of land to farm in the 1940s. Not surprisingly, this was not a popular project with the Mohave. However, at this point many tribal members are of mixed ethnic origin, including Hispanic.

Today, the Colorado River Indian Tribe's (CRIT) primary industries are agriculture (crops requiring no refrigeration, such as wheat, cotton, hay and onions), light industry, and tourism/river recreation. The tribe owns the Bluewater Resort and Casino, a popular boating and gambling destination. Eighty four thousand acres of the reservation are under cultivation, and the tribe has a 717,000 acre feet water allotment from the Colorado River, almost 1/3 of the entire state's allotment. Not all of this water is currently used. The primary town is Parker, Arizona, with a population of about 4,000.

The climate of the region is very hot, with temperatures reaching over 100 °F from mid May through mid October, and temperatures over 110 °F not uncommon in the summer. Winters are beautiful, attracting many "snow bird" winter commuters. At most, the region may experience a week of light frost a year.

The region is also very dry. The historic average yearly rainfall is less than four inches, and recent years have proven to be even drier. Summer rains, called the monsoons, are often spotty, with some areas receiving a deluge, while others just miles away remain totally dry. The winter rains tend to be more widespread and gentle.

Agriculture brought to the community some financial independence and improved infrastructure, but also degraded wildlife habitat, increased soil salinity, and increased fires. With fire came the loss of the traditional mesquite bosques used in traditional Mohave ceremonies and a massive saltcedar (*Tamarix* spp.) incursion.

Saltcedar has been found to bloom in the area 12 months out of the year, can use up to 200 gallons of water per day per tree, is fire and flood adapted, increases soil salinity and is estimated to infest 1.5 million riparian acres in the Southwest. It is not, however, a no man's land for wildlife, and the endangered Southwestern Willow Flycatcher has been found to nest in saltcedar as a alternative to its degraded or non-existent traditional willow habitat.

The Preserve

The 'Ahakhav Tribal Preserve, located on the CRIR, was established in 1995 and has been maintained through grants from many different federal and state agencies. It consists of just over 1,000 acres situated along the Lower Colorado River. Its three goals are recreation, restoration and education. The Preserve receives a small operating budget from the tribe, but otherwise is solely dependant upon grants.

Over 400 acres of land have been revegetated on the Preserve. This revegetation has consisted of mechanical removal of saltcedar, soil testing to determine appropriate native plants for revegetation, planting of native willow, cottonwood and mesquite, and drip irrigation until the plants are established. Additionally, an old backwater channel has been dredged out and restored for fish habitat, swimming and canoeing, ('ahakhav is the Mohave word for backwater) and a four acre grass park area with picnic tables and BBQs has been established. The preserve has been featured in *Native Peoples Magazine, Arizona Highways Magazine, Landscape Architecture* and several restoration journals.

The Nursery

The 'Ahakhav Native Plant Nursery was established in 1996 to provide native plants for the Preserve's restoration efforts. Over time, the nursery increased production to provide native plants for other restoration efforts on the reservation, and is now also providing plants for restoration projects along the Lower Colorado River in Arizona. The nursery now includes low water use native and xeroscape plants for retail sale as well.

The staff includes a nursery director and up to six part time nursery workers in the busy winter and summer months. Tribal members are hired when possible.

The nursery grows plants in 1, 5, and 15 gallon black plastic containers, propagated from seed, cuttings, or purchased liners. We grow eleven native species used for revegetation, eleven additional natives used in more conventional landscaping, and approximately 40 additional species for retail sale. We currently have room for approximately 50,000 one gallon containers.

Typically, southwestern Arizona nurseries do not have greenhouses. We are no exception. Plants are either grown out in the open or under two large shade structures, which help to keep the soil temperature down in the summer. The irrigation system is a simple modified home lawn sprinkler system, mostly on 2.5 foot risers. Pots are placed on salvaged wood pallets, which are in turn on top of coarse gravel. Soil mix consists of 50% sand and 50% inexpensive bulk wood mulch. No sterilization of pots or soil is performed.

Our most common restoration plants are western honey mesquite (*Prosopis glandulosa* var. *torreyana*), screwbean mesquite (*Prosopis pubescens*), Fremont cottonwood (*Populus fremontii* var. *fremontii*) and sandbar and Goodding willow (*Salix exigua* and *S. gooddingii* respectively).

Species

Western Honey Mesquite

Propagation

Harvest seed pods in late June/early July. Minimize bruchid insect damage by picking pods when ripe and dry but before dropping to the ground. Store in airtight containers once seeds are thoroughly dry (not a problem during our 115 degree summer days). Grind seed pods in blender and sift out "flour." Break open remaining individual shells and remove seeds. (Similar to cracking sunflower seed shells.) We use needle nose pliers. Scarify seeds with sandpaper. Soak in water 24 hours. Plant seeds that swell, (you can dry off and rescarify those that don't) one per one gallon pot, at a depth of about double seed diameter. Plant seeds early

May through July/August, or anytime temperatures are over 90 degrees. Protect from rodent herbivery with hardware cloth until plants are a few inches tall.

Advantages/Disadvantages to Western Honey Mesquite

Advantages: The most drought tolerant of restoration species discussed here. Good salt tolerance. Great for wildlife. Many animals from deer and coyote to rabbit eat the pods.
Disadvantages: Problems with psyllids (small insect similar to aphid.). Problems with browsing, especially by rabbits, both in nursery and in outplantings. Seed preparation is extremely labor intensive.

Success

Up to 95% germination rate within 5 days. Loss of 5% to 10% to rodent browsing, even when fenced and covered with hardware cloth. If planted in May, ready to outplant in four months (over 12 inches tall). Normally planted the following spring , prior to summer growing season. Our nursery has propagated over 7,000 Honey Mesquite.

Screwbean Mesquite

Propagation

Harvest, storage and planting times are identical to Western Honey Mesquite. Seed preparation is not as labor intensive. Seeds are much smaller, slightly larger than a mustard grain. The grinding process also serves to scarify. Once pods are ground, resulting flour/seed mixture can be rinsed in water to remove some of the flour, soaked for 24 hours, and planted one pinch per one gallon pot (approximately 2 to 3 seeds per pinch).

Advantages/Disadvantages to Screwbean Mesquite

Advantages: Does not suffer browse damage. Does not suffer major insect damage. Good salt tolerance. Much less intensive seed preparation.
Disadvantages: Needs to be within eight feet of water table to survive. Truly a riparian species. Not as readily used as food source by wildlife.

Success

Percent germination is lower. Around 80% within 7 to 10 days. Old seed does not germinate as well. Growth rates are more variable. Because seed preparation is easier, we replant ungerminated pots every two weeks. If grown under shade, May plantings are ready to outplant by October. Normally planted the following spring. Over 15,000 Screwbean Mesquite trees propagated at our nursery.

We use no fertilizer on any mesquite as they are nitrogen fixing legumes and no positive effect has been shown when they are given fertilizer. Rhizobium inoculant is quite successful for boosting growth on mesquite.

Fremont Cottonwood

Fremont cottonwood was once the dominant riparian tree species on the Lower Colorado, along with Goodding willow. A short-lived, fast growing tree, groves were over harvested for construction lumber and steamboat fuel in the early part of this century. Cottonwood/willow no longer naturally regenerates due to altered flood regimes caused by the extensive damming of the Lower Colorado. Fremont cottonwood has a low salt tolerance (but better than Goodding willow) and needs to be very close to the water table to become established. It should be noted that even aged stand plantings, a common restoration technique due to limited funds and a short term planning strategy, do not provide any understory once trees are mature.

Propagation/Success

Trim lower branch "whip" cuttings from 2 to 6 year-old trees from November through January. Whips should be 0.5 to 2 inches in diameter. These whips are a limited resource in our area, and there are different cottonwood phenotypes that have radically different bloom times. Trim off all side branches/leaves and cut whips down to 12 inch lengths. Keep in water. Can be held for up to two weeks. Dip end in 0.1% IBA powder and push pole into 1 gallon pot about three-fourths of the way down. Firm soil around pole and keep very wet. Plant 20% over required quantity. We have an approximately 15% failure rate. Poles should root within three weeks. Leaf out depends on particular phenotype and occurs anytime from January to March. Fertilize with slow release fertilizer. We use Best Tabs 20-10-5. Ready to outplant by April 15th. This process has been accomplished successfully in the summer as well.

Goodding and Sandbar Willow

Goodding willow is a large tree originally found growing in mixed stands with Fremont cottonwood. Currently very limited on the reservation. Sandbar willow is a 15-foot-tall shrub, creating dense stands due to root suckering. It is a

great understory for a mature Goodding willow/cottonwood canopy.

Propagation/Success

Process is identical to Fremont Cottonwood, and takes place at the same time of year. Sandbar willow has an extremely high rooting rate from 1-year-old wood cuttings (in other words, >95%). Is IBA really necessary? We don't know but why risk it? Finding a source for cuttings is sometimes quite difficult. Over 30,000 Fremont cottonwood and Goodding and sandbar willow have been propagated at our nursery.

Propagation of Willow and Cottonwood from Seed

Goodding willow was successfully grown from seed in the summer 2000. Fresh seeds were mixed with damp sand and spread over a plug tray. Seedlings were transplanted when they had two true leaves. Ready to be outplanted the following spring.

Advantages/Disadvantages of Propagation from Seed

Advantages: Increased genetic diversity of a particular phenotype. Easy to propagate large numbers of seedlings. Ensured ratio of male to female trees. Disadvantages: Short seed viability. Longer grow out period. Seeding and transplanting takes place in the heat of the summer, a distinct disadvantage when it's 115 °F in the shade.

The Future:

Coming to an ecosystem near you...

Saltcedar and other noxious weeds will continue to spread. The natural flood regime will NOT be restored to the Lower Colorado River, thus ensuring ongoing revegetation efforts into perpetuity. Federal, State and Local governments and Tribal entities will continue with efforts at restoration/revegetation. Native plants will continue to increase in demand.

The Colorado River Indian Tribes will make a decision.

Because of the way that the 'Ahakhav Native Plant Nursery came about, almost as an afterthought, it has received very little support from the CRIT. All nursery expansions have been paid for from nursery profits, the Nursery Director position has no benefits, and equipment is limited. Early profits were based on highly inflated plant prices (attainable since we were buying the plants from ourselves, or because we were the only available option to other organizations). The growth of the nursery has not gone unnoticed by other tribes and outside enterprises. The CRIT will soon have to make a decision. They will either fully recognize the 'Ahakhav Native Plant Nursery as an important and viable tribal enterprise and support it financially and politically, or increased competition from outside nurseries including competing tribal enterprises will make the nursery a losing financial proposition and it will not continue.

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People doing work on Southwest riparian restoration.

Julie Stromberg, Arizona State University. Many published pieces. Good information on natural regeneration of cottonwood/willow at the Nature Conservancy's Hassayampa River Preserve in Arizona.

Contact Imperial and Cibola National Wildlife Refuges in Arizona, and the Bosque del Apache National Wildlife Refuge in New Mexico to learn about their ongoing restoration projects.

Contact Dr. Bertin Anderson of Revegetation and Wildlife Management Center, Inc., 203 South Palm Drive, Blythe, CA 92225 (760) 922-2541. Dr. Anderson has been doing work in the Southwest for over 20 years. He is a bit prickly to deal with at times, but probably knows more than just about

anyone about southwest riparian restoration issues. Just resign yourself to getting some stories to go along with the facts you are looking for. Try looking up his journal articles first.

Further details on these and other plant protocols for the 'Ahakhav Native Plant Nursery can be found at the *Native Plants Journal* website hosted at the University of Idaho. http://www.nativeplantnetwork.org.

RED LAKE FORESTRY GREENHOUSE PROGRAM

GLORIA WHITEFEATHER-SPEARS

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Keywords

Dawes/Nelson Acts, forest development programs, Wright Report, restoration

In 1916, The Red Lake Indian Forest Act was created. The Red Lake Band of Chippewa in Minnesota stood alone and refused to consent to allotment. Consequently, The Red Lake Band is the only tribe in Minnesota for which a congressional act was passed to secure a permanent economic foundation for the band and its future.

Over the years and back in history, through two "cessions" beginning in 1863 and relating to the Dawes/Nelson Acts of 1887-89, millions of acres of tribal timber land were coercively taken from The Red Lake Band.

The Nelson act promised that the government would determine the quantity, quality, and full fair market value of timber on 2.9 million acres. Sale proceeds would be deposited for the Band into a "Nelson Act Trust Fund" to earn 4% interest for 50 years. The story of what actually happened to the 2.9 million acres is one of many broken promises. Nothing was done to determine the quantity, quality, and value of timber. In fact, much of the timber was essentially given away to greedy Minnesota logging companies.

Among forest scholars, the manner in which Minnesota logging companies acquired The Band's ceded timber is known to be one of the greatest timber frauds that ever occurred in the history of the United States. The Red Lake Band filed a lawsuit on August 2, 1951, for 13 claims for damages because of the way in which the United States had treated it unfairly or dishonorably.

In 1954, the government initiated a Forestry Management Plan, which was very limited. Very little was done to require the government to perform its forest management activities. Meanwhile this case was being litigated.

In 1977 the federal government funded Forest Development programs for Tribes across the United States. Tribes complained because there was not enough money being provided to reforest acres that were cut.

In 1978, the Red Lake Forestry Greenhouse was built by tribal members. The greenhouse was originally built in Red Lake but was moved and rebuilt in Redby in 1980. Expansion took until the fall of 1981 to get to its present size of 68' x 96'. Total capacity per crop is currently at 325,000 seedlings. We grow 2 crops per year for a total of 650,000 seedlings per year. An average of 400 acres is planted annually. Overall total seedlings grown to present is over 13,000,000.

In 1983, the Wright Report documented continuing failures by the government to manage The Red Lake Indian Forest in any meaningful way.

In 1997, The Bands first 5 Nelson Act claims were settled by payment to the Red Lake Band in the amount of $27,105,000. The claims were for tribal land and timber that was undervalued and the 4% interest was not paid. The 8 remaining claims concern the mismanagement of the Red Lake Indian Forest and mismanagement of Tribal Trust Funds connected to the sales of the reservation timber.

Combined total sought for all 8 claims is $494,559,216.

The Red Lake Band alleged that the government failed to manage and care for the Red Lake Indian Forest in accordance with the principles of scientific forestry as required by the 1916 Act of Congress creating the forest. As a trustee of the forest, the government should have properly managed the forest so that there would be successive crops of valuable timber and should also should have accounted for all monies it collected from timber-related activities. But it did not do this.

The claims are as follows:

- **Claim 6**. This claim is for the difference between the value of the timber in the Red Lake Indian Forest as it exists today and as it would exist, had the government done a proper job. This included profits lost because the government failed to engage in commercial thinning of the pine site area.
- **Claim 7**. This claim concerns the failure of the government to properly manage the lands outside of the Red Lake Indian Forest but inside the Red Lake Indian Reservation. The Band alleges that the value of timber outside the Red Lake Indian Forest is less valuable because of improper management and that this resulted in a loss of profits that could have been earned from proper commercial thinnings.
- **Claim 8**. Apart from the Nelson Act, 4 other trusts were established for the Red lake Band. Two of these trusts were established to receive funds from the disposition of timber and interest earned therein. Two additional trusts were established to receive proceeds from Red Lake Indian Labor. The claim is for reimbursement for improper expenditures from these 4 trust funds.
- **Claim 9**. This claim relates back to claim 6, since the band lost profits in the way of unrealized commercial pine thinning revenues, and since the 1916 Act required that these profits should have been deposited into a principle trust fund at 4% interest. The Band is also entitled to interest income damage from these lost profits.
- **Claim 10**. This claim arises from the government's failure to credit deposits and interest receivables into the Bands trust funds. Under this claim, The Band alleges damage from the loss of interest income from the failure to post these deposits and the loss of the ability to "sweep the accounts" over night.
- **Claim 11**. This claim asserts that the government's failure to properly manage the Red Lake Indian Forest also includes a failure to deposit net stumpage sales proceeds to the Bands trust accounts.
- **Claim 12**. The government sold Red Lake Indian Forest pine timber to the Red Lake Indian Mills at less than fair market value. In doing so, it did not do what was in the best interest of the Band. Because money from the sales to the Red Lake Indian Mills was required to be deposited into its 4% trust fund, the Band lost money this way, too.
- **Claim 13** relates back to claim 9. It is for interest income losses from profits lost as a result of the government's failure to thin the pine site area outside the Red Lake Indian Forest. Under a separate statute, the government as a trustee of forest lands is required to invest income from net harvest sales. The Band lost money from the government's failure to invest properly.

The likelihood of winning a case depends in large measure on what courts have done in similar cases in the past. This is called Historical Precedent. When we look at decisions made in the United States Court of Federal Claims, we see a meager history of adequate recovery in claims against the United States Government, particularly with respect to timber claims. The court is willing to go far indeed to create novel theories of law to avoid making very large awards in timber cases. And so, despite having a basis that will support a prima facie case of damages of over $400 million, the general history of Indian Claims cases which have gone to trial in the United States Court of Federal Claims indicated overwhelmingly that a resolution at trial resulting in an award commensurate with such damages is extremely remote. Finally, when comparing this history with the fact that the proposed settlement amount exceeds any recovery ever received by a single tribe in the history of the United States Court of Federal Claims, and in fact, is one of the 20 largest awards ever, regardless of the

kinds of cases, the dimension of the settlement proposal becomes very significant.

The case itself has been in litigation since 1951; nearly a half a century. There is no other case like it.

The Award won by the Red Lake Band of Chippewa Indians is for a total of $53,500,000.

A major reason that led to the government's willingness to settle is its unwillingness to have to restore the Red Lake Indian Forest. It is their resistance to any obligation toward restoration of the Red Lake Indian Forest that has led to their insistence on the establishment of a permanent fund. Not only is remediation an expensive process, it is a painstaking process.

It is precisely the government's insistence on a permanent fund that can provide the way to fund a plan of remediation of the Red Lake Indian Forest. The resolutions and ordinance establishing the permanent fund authorizes the use of the monies on a priority basis for: 1) restoration of the Red Lake Indian Forest; 2) for other natural resource restoration; 3) for other purposes to benefit the band as may be determined by the Tribal Council.

Of the $53.5 million, $40 million has been placed in a permanent fund. The Red Lake Band of Chippewa Indians has hired a private investment firm. This fund will be used for reforestation activities that will provide economic opportunities for all members of the Band. The plan of operations of the permanent fund provides important protections with respect to utilization of the funds.

The fund will be owned and controlled by the Band; the Secretary of Interior may not make changes in the utilization of the fund. Changes may not be made to the Resolutions or Ordinance creating the fund without approval of the Secretary of the Interior, whose approval may not unreasonably be withheld. The Secretary's role in any such process is that of trustee. He may not substitute his judgment of what is best for the Band, and the establishment of the permanent fund does not absolve the government of its on-going obligations under the 1916 Act after the date of settlement.

The original pine acreage for The Red Lake Indian Forest was 60,000 acres. Only 10,000 acres are left today.

Some of the things the Red Lake Band of Chippewa Indians and The Red Lake Forestry Program have done include:

- **1996**: A Forest Policy/Advisory Committee was formed at the request of the Tribal Council because of stumpage issues.
- **1997**: The Red Lake Band of Chippewa Indians went to Self-Governance.
- **1999**: The Red Lake Forest History book was written.
- **1999**: The Red Lake Fire Management Plan was completed.
- **2000**: The Integrated Resource Management Plan was completed.
- **2001**: The Forestry Technician School on The Red Lake Indian Reservation through Northwest Technical College was completed. Training will be held at the Whitefeather/Moe Education Complex, also known as "New Beginnings" building. Classes began August 20, 2001. This is a 2-year program for a Forestry Technician certificate (33 credits) for 20 students. Four students out of the original 20 students will be selected to continue their education for a 4-year degree through a University.

In the works is the Red Lake Forest Management Plan.

The Red Lake Band of Chippewa Indians and the Forestry Department are planning ahead by instituting the Forestry Technician school and the building of the New Greenhouses & Fire Facilities with future expansions included. Construction is planned to begin in Spring 2002.

By the year 2006, we will begin reforestation work on the Red Lake Indian Forest. The Red Lake Band of Chippewa Indians has plans to reforest the Red Lake Indian Forest at the rate of 1,000 acres per year for the next 50 years. Overall projections of this major project will take time to implement. A 20% increase per year from 2006 to 2011 of all Forest Development activities will be implemented. Twenty-seven additional positions will be developed to manage its resources.

At this time I would like to thank these people for their expertise in helping the Red Lake Band of Chippewa Indians and the Red Lake Forestry Department with their future plans in reforestation.

Dr. Tom D. Landis, National Nursery Specialist, who gave us information on contacts of people to call and ask if they would be interested in helping us with our developments and research. Also for providing funds to help with consultant fees and travel scholarships for 2 students.

Dr. Richard W. Tinus, U.S. and international expert in tree seedlings and greenhouses, who came to visit with us. Dr. Tinus did a critique on our existing facilities, looked over potential proposed sites for new facility, gave us ideas for the new facility, initial planning for a new facility, and other alternatives in reaching our goal of planting 1,000 acres per year for 50 years. Dr. Tinus was introduced on our behalf to the Red Lake Tribal Council where he discussed our present and future plans.

Mr. Dick Rose, Landscape Architect, who developed the proposed site plan for the utilization of the proposed 40-acre site next to the Red Lake Elementary School in Red Lake. Also for continued support with budget predictions and his willingness to help in many other ways.

Dr. Kas Dumroese, University of Idaho, who looked into research done with growing tree seedlings with the ebb & flow system.

Dr. Ron Overton, Regeneration Specialist, Purdue University, for always listening and helping us to make connections to other experts. Also for the opportunity to host part of "The Russian Forester Delegation" at Red Lake.

Our Greenhouse Task Force, who is a mixture of tribal planners, grant writers, realty, historian, foresters, architects, engineers, plant physiologist, greenhouse manager and all others who have input and been working hard over the past 1 1/2 years.

Mr. Eric Stuewe, Stuewe & Sons, Inc., who is always interested and helpful in production of tree seedlings with insight to other people and businesses.

Dr. John Bartok Jr., Agricultural Engineer and Greenhouse Consultant, who is happy to work with us by providing overall insight regarding developments, design, planning, and whole concept of greenhouse operations.

Summary Table.

YEAR	EVENT	RESULT OR INTENT
1916	Red Lake Indian Forest Act	Congressional act passed to secure a permanent economic foundation for The Band
1863		Cession of Tribal land
1887-1889	Dawes/Nelson Act	Further cession of 2.9 million acres ofTribal land
1951	Lawsuit filed by Red Lake Band	13 claims made against the US government
1954	Forestry Management Plan	Limited government responsibility
1977	Forest Development Funds	Very little money given to tribes
1978	Red Lake Greenhouse	Built by Tribal members
1983	Wright Report	Documented continuing government failuresto the Tribes
1996	Forest Policy/Advisory Committee formed	Dealt with stumpage issues
1997	Red Lake Self-Governance	Ceded Lands Settlement ($27,105,000)
1999	Red Lake Fire Mgt. Plan Red Lake History Book	
2000	Red Lake Integrated Resource Management Plan	
2001	US Court of Federal Claims Decision Red Lake Forestry Technician school	8 remaining claims settled for $53.5 million $40 million permanent fund established Education for Tribal members

Design and Layout of a Small Commercial Greenhouse Operation

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Abstract

This information sheet outlines the major requirements and factors that should be considered by someone contemplating starting a small greenhouse operation for the production of tree seedlings, nursery stock, perennials, herbs or other specialized crops. It can also be used when planning an expansion of an existing business.

Key Words

Greenhouse design, greenhouse environment, greenhouse lighting, irrigation, fertilization

Site Selection

The following are considerations for site selection listed in a general priority of importance:

Adequate Land

A minimum of 2 acres is needed to allow for facilities, outdoor growing area, access, parking and buffers. Availability of additional vacant land adjacent to the site is desirable for expansion as the business grows. Soil type should provide good drainage.

Quality Water

The amount of water needed depends on many factors including climate, irrigation systems used and crops grown. Water supply should be adequate to meet peak load demands. Tests should be conducted to evaluate water quality for suspended sediments, pH, electrical conductivity, total dissolved solids, alkalinity and hardness.

Orientation

Good solar access is needed throughout the day and year to get enough light energy for photosynthesis. Shelter belts to the north can provide wind protection and energy conservation.

Topography

A site that has a gentle slope to the south increases solar gain and provides drainage of rain and runoff. A fairly level site with a 1% to 2% slope reduces site preparation costs.

Road Accessibility

For wholesale operations, good access to the interstate highway system can improve delivery of supplies and shipping of plants. In retail operations, location on a heavily traveled road will increase the customer base and improve the visibility of the business.

Utilities

The cost of providing electricity and telephone to the site should be considered. Where extensive greenhouse operations are to be installed, the type and availability of fuel may be a concern.

Regulations

Federal, state, and local regulations will influence what can be done and how long it takes to get approval. Zoning, building and wetlands regulations should be checked before selecting a site.

Site Layout

Facilities Master Plan

A master plan provides a framework for orderly construction of the property and should be based on a sound business plan. The plan starts with a survey of any existing facilities, evaluates the benefits and constraints of the site and establishes where new facilities should be built. A good arrangement is to plan a core area which contains the propagation and production greenhouses, headhouse, storage and parking. Outdoor production areas should be located nearby for efficient plant movement and shipping. Expansion space should be planned for all areas. It is best to do the planning on paper so that several alternatives can be evaluated.

Parking and Access

Good, all weather vehicular access to the buildings and growing areas should be provided. Parking for employees and customers, convenient to the core area is desirable. An adequate number of parking spaces for retail sales may be needed to meet the zoning code. A paved surface is usually required. Other areas and driveways can be unpaved. Surface can be bank-run gravel, pea stone, crushed stone or trap rock. Driveways and parking areas should slope to provide drainage. Swales or underground piping is necessary to carry the water away from the area. Swales should be grassed and slope at least 0.25"/ft.

Storage

An area for storage of materials including soil mix, containers, chemicals and equipment is needed. Indoor storage for some items is desirable for easy access and protection from weather. This can be in a headhouse or separate building. An outdoor area is usually provided for growing mix. Space for an equipment storage shed with a shop for maintenance should be planned. A clear span pole building is a low-cost alternative.

Production Areas

Prime space should be allocated to plant production including growing beds, shadehouses and overwintering structures. Good light, drainage and proximity to water are needed. Production areas should be laid out in rectangular blocks of 1000 to 2000 sq ft. Within the blocks, 6' to 8' wide beds are placed adjacent to 2' wide walkways. Generally an arrangement with shorter length walkways across the block is preferred over ones with walkways that run the length of the block. Roadways are placed between blocks to transport and maintain plants. These should be 15' to 20' wide to allow movement of trucks or tractors. Gravel or stone on the surface requires a minimum of maintenance.

Greenhouses

A key to successful production is a well-designed greenhouse with good space utilization and accurate environment controls. Greenhouses can be classified as free-standing or gutter-connected.

Free-standing Greenhouse

A free-standing greenhouse can have a quonset (hoop), gothic, or gable roof shape. The quonset is usually the least expensive and is available in widths to 34'. Gothic designs have higher light transmission and shed snow easier. Gable designs may use trusses to span a width up to 60'.

The free-standing design is usually the best choice for the small grower planning on less than 10,000 sq ft of growing space. It is easy to build additional greenhouses as more space is needed. A separate growing environment can be provided in each house. Individual greenhouses can also be shut down when not in use. They are also better suited for heavy snow areas and non-level sites. Free-standing greenhouses are less expensive to build as site preparation and erection costs are less.

Gutter-connected Greenhouse

This is a series of gable or quonset arches connected together at the gutter level. Individual bays vary from 12' to 25' in width and have a clearance of 8' to 16' at the gutter. Bays can be put together to get the width desired.

A gutter-connected greenhouse offers the greatest flexibility. The vertical sides give good space utilization and gutter height of at least 12' provides an air buffer and room for an energy truss and shade/blanket system. Gutter-connected greenhouses are usually most efficient and economical in a size of at least 10,000 sq ft. Heat can be centralized and heating costs are as much as 25% less than an equal area in free-standing greenhouses. Utilities are centralized and easier to install. Be sure to provide space for future

expansion, as most businesses tend to grow rapidly.

Glazing

Double poly is a low-cost material with a 4-year life. Corrugated polycarbonate is a more expensive alternative with a life of 20 years. Polycarbonate and acrylic structured sheet glazing provides greater insulation but increases initial cost. Although initially more expensive, wide pane glass is the preferred glazing where high light levels are required during the winter. Energy blankets can help to reduce heat loss and also provide shading during the summer.

Layout

A headhouse, either one section of the greenhouse or an attached building, is desirable. It should contain a work area for flat filling and transplanting, receiving and shipping area, utility room, office and employee room. Build it high enough so that storage can be overhead. Adequate water, electricity and telephone should provide for an expansion phase.

It is best to have concrete floors throughout the headhouse and greenhouse for cleanliness and access. Adequate drainage should be provided.

Depending on the crops to be grown, production can be on the floor or on benches. Fixed peninsula benches or a moveable bench system may be used to increase growing space. A system of carts or overhead trolley conveyors can be employed to reduce material handling costs.

Germination Rooms

Germination can be done on the benches in the greenhouse, but it is better to have a separate room or chamber. Good heat control and a fog system can provide the ideal environment. Lighting can give the seedlings a good start once they germinate.

Environment Control

Heat

A hot water boiler is the best choice for a heating system. Water temperature can be modulated to meet the needs of the different systems. Each greenhouse or bay should have independent temperature control for different crop needs. Hot air furnaces or unit heaters are a good choice where the greenhouse will be shut down for the winter as water systems need to be drained.

Bottom heat in the floor or under the benches is important for uniform root zone temperature. Floor heat can be provided with EPDM tubing placed in a sand layer or in concrete. Bench heat can be provided with either EPDM tubing on the benches or low-output fin radiation under the benches. It is best to limit this zone of heat to no more than 20 BTU/sq ft as excessive drying of the growing mix can occur. Water temperature should not exceed 100 °F. Root zone heat will provide only about 25% of the total greenhouse heat needs on the coldest night in northern climates. Heat exchangers or fin radiation around the perimeter and under the gutters are installed to provide the remaining heat. These should be zoned separately.

Cooling

Natural ventilation depends on temperature and wind gradients to remove the heat from the greenhouse. Locating the greenhouse where it can intercept the summer breezes and providing large roof and sidewall louvers is important.

A fan and louver system will give more positive ventilation. Although more expensive to operate than a natural ventilation system, it will give better temperature control. The system should be designed to give a ventilation rate of about 2 cfm/sq ft during the winter and 8 cfm/sq ft during the summer. Several stages of ventilation capacity are better than a single stage.

Evaporative cooling, either fan and pad or fog may be necessary if plants will be grown during the summer. The moisture provided picks up excess heat that is exhausted by the fans.

A horizontal air flow (HAF) system will give good air movement and uniform temperatures. Small fans are placed to develop a horizontal pattern of air movement that mixes the air, removes moisture from leaf surfaces to reduce disease potential, and increase carbon dioxide to the plants.

Energy Conservation

With the high cost of fuel, installation of energy conservation measures is important to reduce production costs. Double glazing, perimeter insulation, energy blankets and wind breaks should be considered. Management practices, such

as growing crops that require cooler temperature, purchasing plugs or prestarted plants, keeping the growing space full and the use of supplemental carbon dioxide can also help.

Supplemental Lighting

To overcome variable weather conditions and still meet a production schedule, supplemental lighting may be needed, especially in the propagation area and nursery. High-pressure sodium (HPS) fixtures are the most efficient and should be installed to provide at least 900 foot-candles at plant height.

Controls

For small operations, a controller should be installed to control heating and ventilation equipment. Computer control is best for integrating the heating, cooling, lighting and other systems in larger operations. It also provides a record of the environmental factors so that timing of the crop can be repeated or adjusted.

Irrigation

Uniform irrigation is very important, especially for plants grown in plug trays with small cells. A computerized boom system can be programmed to water different sections of the greenhouse at different rates. These units are very versatile and will eliminate most hand watering.

Other systems used in greenhouses include mist for propagation areas, overhead watering for mature crops and drip for hanging baskets and crops grown in ground beds. Capillary watering mats may be best for potted plants grown on benches. Ebb and flood watering is becoming popular for bench or floor systems where uniform watering and containment of the nutrient solution is desired.

Pesticide and Fertilizer Storage

Separate cabinets or sheds located away from work and growing area should be used to store pesticide and fertilizer materials. They should have heat to prevent liquids from freezing and ventilated to remove hazardous fumes. Personal protective clothing and spray equipment should be stored separately.

Installation of a well controlled greenhouse will pay for itself in better quality, greater production and more uniform plants. Be sure to plan all systems for expansion.

MAPUCHE MEDICINAL PLANTS: PROPOSITION IN THEIR PROPAGATION

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Abstract

The Mapuche (native indians from Chile) population is one of the largest populations of native indians left in America (approximately 1 million). As many of the other Native communities, they continuously struggle to maintain their rituals and customs. One of the most valuable customs for the Mapuche is the use of medicinal plants. All these plants are native plants from the southern area of Chile and some of them are now hard to get. Two workshops were done with a group of Machis (Mapuche medicine woman), in order to determine the species they used the most and the scarcity status of these plants. From a list of 24 species, 10 were found in the red book of endangered species from the Government of Chile. A proposal for future work in propagating these species is given at the end of the paper.

Key Words

Medicinal plants, Mapuche, Machi, endangered species, propagation, medicinal plants

A LITTLE BIT OF HISTORY

In order to understand the present situation that the Mapuche people are living in Chile, we need to go back in time at least 500 years. In 1536, the Spaniards arrived for the first time to Chile. They went from Peru to Argentina, crossed the Andes Range and found only Native Americans, mountains, forests and, unlike Peru, there was no gold (Villalobos 1982). These Spaniards went back to Peru and spread the word that going to Chile was not worthy—no gold, only miseries. Nevertheless, in 1541, another expedition went from Peru to Chile through an easier route—the desert. They then founded the first city in Chile—Santiago (our capital today) (Villalobos 1982). Their idea was to colonize and have the native Americans as their slaves. Obviously the indigenous communities did not like this and a long war started. The northern indigenous communities didn't last very long and soon enough the Spaniards conquered them. In contrast, the Mapuches, located in the southern region of Chile (Figure 1), were numerous and good fighters and resisted the invasion for 100 years. In fact, in1641, the Spaniards renounced the idea of colonizing the area of Bio-Bio to Temuco, and the King of Spain officially gave that land to the Mapuches as a separate, independent territory (Villalobos 1982).

Until early 1800, life was peaceful between Mapuches and Spaniards. The Chileans (people born in Chile were mainly descendants from Spanish colonizers) decided to be independent from Spain and succeeded in creating the Republic of Chile in 1810—in other words, the political, territorial and legal jurisdiction of the land and their people (Bengoa 1985). At that time, they realized that the Mapuche lands divided Chile in two, threatening the continuity of the sovereignity of the republic. They even feared that other

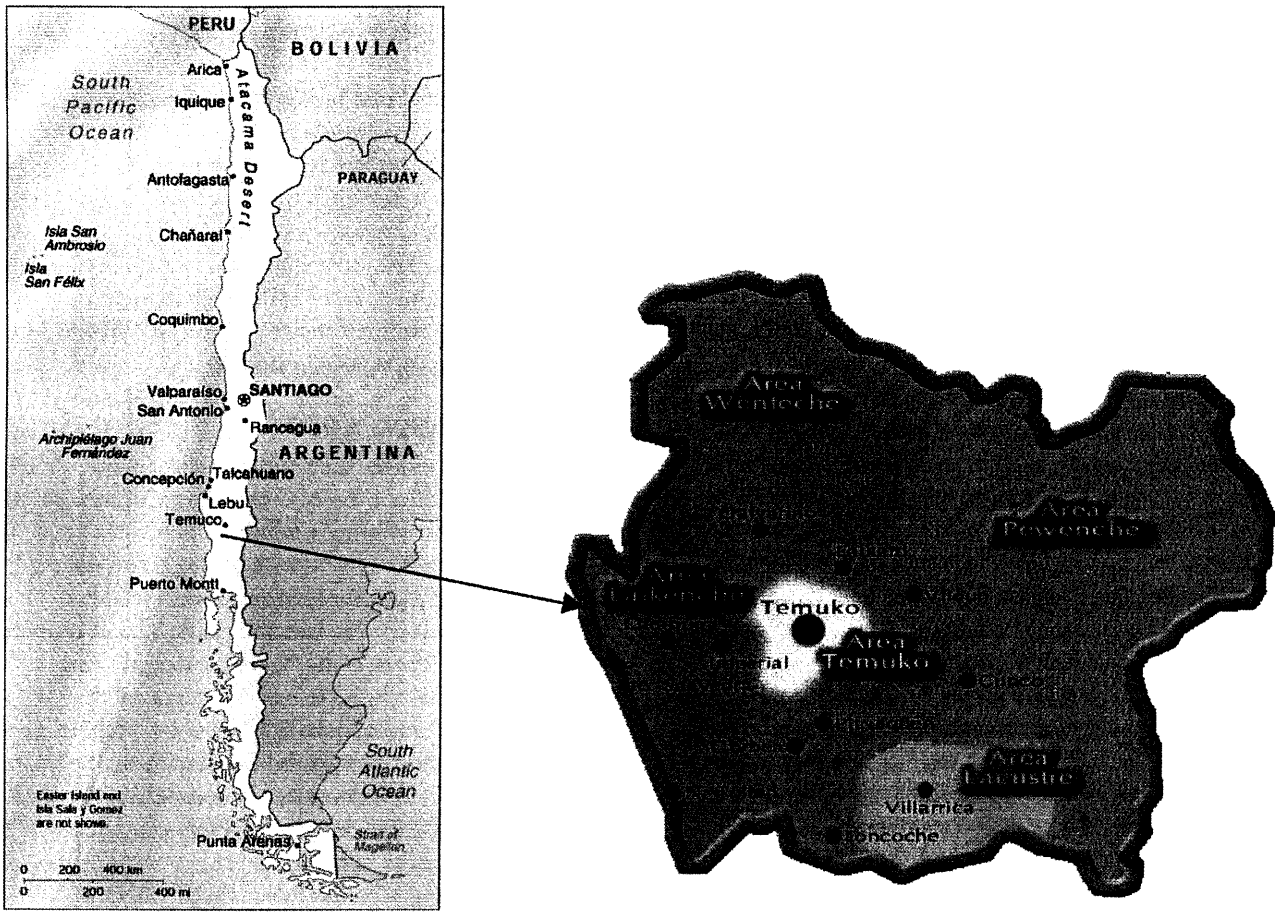


Figure 1. Map of Chile (left) and map of Temuco (right) and how the territory is divided according to the Mapuche people.

countries could claim this territory as theirs. In 1859 the Chilean government officially tried to incorporate the Mapuche territory into the rest of Chile by giving, buying, or renting some of these lands to foreign settlers (Bengoa 1985). But the Mapuche had a different concept of land property and, for them, they could not sell or give their lands. Lands were given to them by their ancestors and the sacred spirits to be part of their communities and families for eternity. They could not be owned as private property of groups, much less of individuals (Casanova 2000). This conflict caused one of the bloodiest wars in the history of Chile where, in 1883, the Mapuche finally surrendered to the Chilean Government and Indian reservations were established (Villalobos 1985). This meant that the Mapuche lost 9.5 millions hectares and only 500,000 were given to them, usually marginal lands. Per community, they received a variable amount of land depending on the amount of people integrating the community—an average of 4 or 6 ha per person (Vidal 2000). The same author states that the Government gave them property titles as communities, not as individuals, and that further along in time some of these lands were stolen from the Mapuche.

Mapuche's World Vision (Cosmovision)

According to a Mapuche Machi Ilda (shaman, medicine women), the only way to work with the Mapuche is to fully understand their cosmovision, their way of seeing the world, nature, human beings and all the forces that interact in the Universe (Machi Ilda 2000). As you can imagine this is a very complex topic that goes beyond the objectives of this presentation. So we'll talk only in general terms and emphasize those concepts that we think are relevant to understanding the use of native plants by the Mapuche community. They understand the Universe (*Waj mapu*) as divided

into at least 4 levels: *Wenu mapu* (heaven), *Ragin Wenu mapu* (upper world), *Puji mapu* (earth), and *Minche mapu* (the underworld). *Puji mapu* would be the analogue of our concept of earth, ground, where all living forms exist (Machi Victor 2000). The same author states that if we look at the *Waj mapu* (Universe) as a whole it's conformed by an infinite amount of equal forces. Each force (*newen*) represents the essence of every thing we find in nature: water, wind, stars and us. We all have the same value, the same amount of force, in their cosmos nothing or nobody is either higher or lower. It's important to understand that for the Mapuche, each one of us has a force, a power (*newen*). We belong to this force. Even though, we all have the same amount of force (in the sense that nobody is higher or lower), we are all different in essence, in our being (*che*) (Machi Victor). There are spirits that help them to gain power and are related to their own selves and others. Those are the spirits of the old woman, the old man, the young woman and the young men, known as the "Sacred Family." When they refer to the different elements of nature, they always talk about the spirit-element—for example, the old woman waterfall, the old man hill, the young man rock, the young woman forest. The sacred family's spirits are in every place and space—they are the interlocutors between man and the forces. They are the ones that have the knowledge of how to cure people, what plants to use and from what places should they be collected (Díaz 2001). So some communities have the spirit of the mountains. Other communities have the spirit of the water. The latter are responsible for calling the rains, and their Machis do the rain ritual (Díaz 2001). They give an immense importance to the places where the plants should be collected, depending on the patient and her spirit, the origin of the sickness and her newen, they choose which plant to use and the place that it should be collected (Machi Ilda and Machi María 2000). The same species but from different sites makes a world of difference. After they find the right plant in the right place, then they need to know when to cut it how to cut it and the influences of the stars and the moon (Machi María 2000).

So, we can see that propagating medicinal native plants is a complex task. The main point is to recover the ecosystems where these medicinal plants were originally found. The idea of having medicinal gardens doesn't appeal to them. As one of the Machis says, "Medicinal plant gardens are no good, they are lies. They don't have the *newen* from our ancestors. I asked if you wingkas (Chileans) really want to help us, why don't you help us to protect the places that have the force, the power, the newen like the *menokos* (wetlands), *lil* (gorge), the *xayenko* (waterfalls)?" They don't have recipes. The same plant doesn't always cure the same sickness. In fact, they mostly use a mixture of plants, mixtures given to the Machi in a dream or a trance (Machi Ilda 2000).

The Scenario Today

Right now, besides the problem of the land property, many of the Mapuche have lost their customs, their cultural traditions. Many of them don't even speak or understand their own dialect as a result of a discrimination process that has been going on for the last 500 years. The Mapuche are divided. There is the "hard or tough" wing that would like to sue the government by the International Indigenous Rights, want all their lands back (the ones agreed upon with the Spanish King in 1641) and economical compensation to all the Mapuche families. The "softer" wing just advocates for the 500,000 hectares given by the first government of the Republic of Chile (in other words, 100,000 ha). The goverment is making some effort to integrate the Mapuche community into the rest of the nation. There is a Commission in charge of buying lands for the Mapuche people even though their funding is limited and therefore some of the land being acquired is still marginal (degraded, high altitude lands, and so on). On the other side, the goverment has made significant changes in the public health system in order to include the traditional medicine for the indigenous communities as an option for them to choose when they go to the hospitals for health problems.

The objectives of this study are to:

- Describe the present situation of the Mapuche by going back in history and into their cosmovision.
- Explain the conservation status of medicinal native plants used by the machis.
- Propose a future plan of action in order to recover some of the original ecosystems where Machis used to gather medicinal plants.

Materials and Methods

Working with the Machis

In 1998, the Intercultural Health Program of the Government of Chile in Temuco contacted the Forestry Department of the Universidad de la Frontera in order to work together in finding solutions for the problem of scarcity in native medicinal plants. As always, there were no funds available for this. Therefore, an extension project was formulated and then won in order to have enough money to start doing some workshops with the Machis and other Mapuche people that are very knowledgeable in the use of medicinal plants (*yerbateras*). The objectives of these workshops were, first of all, to get to know each other and build a relationship of trust between the Machis and us. They were extremely distrustful of the *wingkas* (white man). It took a long time for them to trust us and to accept working with us. They know that there are many out there trying to get their knowledge of medicinal plants in order to get new royalties or to sell them to the big drug commercial labs. So the first year a workshop was done. They then were invited to visit the Department of Forestry to see what we were doing, visit the greenhouse and see how we produced seedlings. We also went to visit them many times to their houses until, by the second year, we finally had built a relationship of trust between us. A second workshop was done where the objective was to identify woody species used for medicinal purposes. The workshop was done in Mapudungun (native language). Intercultural facilitators were hired in order to translate all the information gathered in the workshop into Spanish. They were recorded and then translated. We also had simultaneous translation while the questions were done. We also did field trips with them to recognize the plants in their natural environment, and observe how they did the ritual of gathering plants.

Results

From that workshop, we identified 24 species that were the most used for medicinal purposes and that had some kind of scarcity problem. From a final workshop, we were capable of identifying the 5 species needed the most and which were almost impossible to find anymore. The whole process of identifying species was very interesting. While they used the Mapudungun names, we used common or scientific names and neither group had a clue what species we were referring to. Then we decided to tell them to bring some samples so that we could identify them. That, plus some field trips, were the solution to the identification process of species. Besides the identification topic, we also mentioned the possibility of making medicinal gardens for them. The answer was clear—they were not interested. The plants would not have *newen* (power) if they didn't grow in their natural environments. The next questions were: Would they allow as to produce this plants for them? Would they like to produce them themselves? The answers to these questions were not so clear. Some of them did not like the idea of plants being produced in a greenhouse. They wanted to transplant natural regeneration seedlings from other forests to the recovery sites, even though many of them had stated before that this technique did not have very good results for them. Others were much more open to the idea of plants being produced in greenhouses, but they did not think it feasible for their own people to grow them. They thought it would be transformed into a commercial activity where only those Machis who could afford to buy them would benefit from it. They would rather have some neutral institution producing seedlings for them at a low price.

Analysis of the results

The 24 species identified initially were compared to the list of flora with conservation problems from the "Red Book," written in 1989, where we found the conservation status of the species. Figure 2 shows that, of the 24 species originally identified, 10 were found with conservation problems. From those ten, 4 were rare, 5 vulnerable and 1 in danger of extinction. Three of the species classified by the Machis as the 5 scarcest plants for them belong to the initial list of 10. There is a high diversity of families. Only 4 families had 2 species belonging to them. All the rest had 1 species (Table 1).

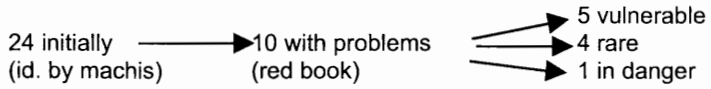


Figure 2. Comparison of the species identified by the Machis, and the list of terrestrial flora with conservation problems (Bernoit 1989).

Table 1. Families, and number of species that belong to those families, identified with conservation problems.

Families	N of species
Buddlejacea	1
Icacinaceae (R)	1
Coriariacea	1
Malvaceae (R)	1
Winteraceae	1
Eleocarpaceae (V)	1
Lauraceae (R)	1
Compositae	1
Apocynaceae	1
Solanaceae	1
Onagraceae	1
Proteaceae (V)	1
Rosaceae (R)	2
Lardizabalaceae	1
Monimiaceae (V) (V)	2
Filesiaceae	1
Grossulariaceae	1
Anacardiaceae	1
Rhamnaceae	1
Cunoniaceae (P)	1

A literature search was done for all the medicinal uses and the parts of the plants used in traditional medicine for the 10 species with conservation problems. The variety of uses are multiple, from the common basic sicknesses such as cold, diarrheas, and constipation to more complex ones such as labor pains, menstrual problems, liver and kidney pains, venereal diseases, and so on. The parts most used from the plants are bark and leaves, with bark as the most important one. Roots and flowers are also used but not as commonly. In few cases, even the savia is used—for earache specifically.

PROPOSITIONS FOR FUTURE WORK

There are 2 main levels of work that is needed in the future. One is on a larger scale, such as regional location of the actual distribution of all the medicinal species used by the Mapuche community, not only from this study but also from previous studies. GIS methodology should be used in order to have only 1 map showing all the different places where species can be found, site conditions and other significant information such as collection methods, and uses. This research should be done year round in order to observe the seasonal changes in yields and plant growth for leaves, flowers, bark, stem and roots.

The other level is a local, more specific scale, where only a few species are studied—in other words, what's know as "case study." The characterizations of certain ecosystems where the species of interest grow are an important part of these studies. They also include the people's perception, traditional knowledge, and basic survival needs. Specifically, in the case of Chile and in the IX Region we think that we should promote the *in situ* conservation of the species and the protection of the habitats. Nevertheless, there is a need for replanting areas and recovering ecosystems so that these 2 methods can complement and support each other in the task of incorporating them into the social economic reality of the communities. Interdisciplinary teamwork appears to be a strong tool for achieving the objectives and the success of the study.

For the natural ecosystems, a characterization will be done in order to have the base line studies of the vegetation and of the site conditions. In those areas where replanting is needed, the efforts will be put into getting propagation material, preferably seeds, that will undergo viability and germination analysis, studies of phenology and vegetative production. We will need to study propagation techniques to evaluate the best fertilization and watering regimes, depending on the site conditions where the plants will be planted. In other words, we will need to create the protocols of production for the chosen species. Finally the establishment phase should also be evaluated, from site prep to planting tools to planting techniques.

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EFFECTS OF PHOSPHORUS AND NITROGEN MANIPULATIONS ON TALLGRASS PRAIRIE RESTORATION

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Key Words

Tallgrass prairie, restoration, nitrogen, phosphorus, big bluestem, Indian grass

The tallgrass prairie biome of North America once extended from Canada to the Gulf of Mexico. Only an estimated 1% of this important ecosystem remains today (Diamond and Smeins 1988; Samson and Knopf 1994), and these remnant prairie tracts are currently the focus of intense restoration and conservation efforts (Bock and Bock 1995; Kindscher and Tieszen 1998). In addition, conservationists have a very strong interest in restoring native tallgrass prairie communities in abandoned farmland tracts that are being allowed to revert to natural vegetation. A variety of prairie restoration methods are currently in use to achieve these goals, including the careful application of controlled fires, watering, re-seeding with native species, and the differential conditioning of grasses and forbs (Schramm 1990; Thompson 1992).

Soil nutrient availability also plays an important role in the establishment and maintenance of native tallgrass prairie vegetation. The tallgrass prairie environment is characterized by high incident light availability, low nitrogen availability, and seasonal water stress, particularly after fire; these conditions favor C_4 grasses, which have higher light-saturated rates of photosynthesis, lower water requirements, and lower N requirements (Turner and Knapp 1996). The growth and nutrient uptake by highly desirable native C_4 grasses such as big bluestem (*Andropogon gerardi* Vitman) and Indian grass (*Sorghastrum nutans* (L.) Nash) tends to perpetuate strong nitrogen-limited conditions, under which they are superior resource competitors (Wedin and Tilman 1990b; Tilman and Wedin 1991).

Native warm-season grasses tend to lose their competitive advantage when soil nitrogen availability is increased (Tilman and Wedin 1991). When soil nutrient cycling in tallgrass prairies is altered by nitrogen fertilization, a decline in the relative biomass of native grasses typically occurs within several years.This change is accompanied by an increase in the relative biomass of weedy forbs, cool-season grasses, and non-native species (Mader 1956; Huffine and Elder 1960; Drawe and Box 1975; Owensby 1969; Owensby and Smith 1979; Wedin and Tilman 1990a,b). Alterations in nitrogen cycling in tallgrass prairie ecosystems due to increasingly high rates of atmospheric nitrogen deposition thus may be a significant threat to the establishment and maintenance of these

important systems (Wedin and Tilman 1990a,1996). In the state of Iowa, for example, concentrations of total nitrogen in rainfall currently may exceed 2 mg N/L (J.A. Downing, Iowa State University, pers. comm.).

Selective manipulations of soil nutrient availability potentially represent a powerful new prairie restoration tool. For example, Morgan (1996) has successfully demonstrated the utility of using organic carbon amendments to deplete the soil system of inorganic nitrogen and facilitate the establishment of native grasses in the prairie provinces of Canada. Furthermore, prairie plant species composition changes significantly in response to phosphorus fertilization (Black 1968; Mason and Miltimore 1972; Wight and Black 1972). Although the mechanisms responsible for this plant community response are still not yet completely understood, it is well known that the relative supplies of phosphorus and nitrogen in the soil strongly influence the nutrient limitation status of the plants. Additions of phosphorus increase soil P availability, and thus should intensify the degree of plant nitrogen limitation. The resulting ecological conditions would be predicted to favor the success of strong nitrogen competitors such as big bluestem and Indian grass. The goal of this study was to explore the effects of experimental nitrogen and phosphorus manipulations on the establishment success of these two native bunchgrass species within replanted tallgrass prairie plots located near Lawrence, Kansas. The data reported here were obtained from a series of experimental 16 m^2 (172.8 ft^2) plots similar to those used by David Tilman and co-workers at the Cedar Creek Natural History Area of the University of Minnesota (Tilman 1987).

Materials and Methods

In spring 1996, an experimental nitrogen availability gradient was established at an old-field site at the University of Kansas' Nelson Environmental Study Area, located northwest of Lawrence, KS. This area was tilled to remove existing vegetation, and the natural seed bank was supplemented with seeds from four dominant native prairie grasses (big bluestem, little bluestem, Indian grass, and switch grass), and two native forbs (Illinois bundleflower and prairie coneflower). These seeds were generously provided by Dr. Kelly Kindscher of the Kansas Biological Survey.

In 1996, the initial design of this study involved the creation of 54, four meter by four meter (13 ft by 13 ft) plots that received nine different nitrogen treatment levels, in sextuplicate. These nitrogen availability treatments included two levels of nitrogen depletion, D1 and D2, which were accomplished using surface soil additions of mixed hardwood and softwood sawdust from a local sawmill (D1=31.25 g m^{-2} yr^{-1}; D2=62.50 g m^{-2} yr^{-1}); a set of controls, C, which received neither sawdust nor nitrogen additions; and nitrogen enrichment levels N1-N6, which received six different supply rates of surface-applied commercial 34-0-0 ammonium nitrate fertilizer (N1=1.0 g m^{-2} yr^{-1}; N2=2.0 g m^{-2} yr^{-1}; N3=3.4 g m^{-2} yr^{-1}; N4=5.4 g m^{-2} yr^{-1}; N5=7.5 g m^{-2} yr^{-1}; N6=9.5 g m^{-2} yr^{-1}).

During the first year of the study, measurements of initial soil chemistry at this site performed by the Kansas State University soils testing laboratory revealed that both nitrate-nitrogen and Bray phosphorus concentrations were near growth-limiting levels, based upon established agronomic criteria. In order to increase the degree of N-limitation in half of the experimental units, three plots from each of the 9 nitrogen availability treatments were randomly selected in spring 1997. Since 1997, these 3 plots (at each N supply level) have also received an additional 11.25 g m^{-2} yr^{-1} of surface-supplied commercial 0-0-18 superphosphate (P_2O_5) fertilizer. The P additions were intended to double the 1996 levels of soil Bray P, and were designated as N+P treatments; the remaining three plots at each of the nine nitrogen availability levels received no phosphorus enrichment, and were designated as N alone treatments.

In addition to the nutrient manipulations above, the 54 plots have been burned annually in the mid-spring of each year since 1996 to remove standing dead vegetation, prevent the invasion of woody shrubs, and inhibit the growth of

cool-season species that initiate their growth early in the growing season. Controlled burns also tend to significantly reduce soil nitrogen availability (Seastedt and others 1991) by volatilizing a significant portion of the tissue nitrogen that is present in the dead vegetation and surface litter layer.

In June-July 2001, the 54 plots were subsampled in order to examine the effects of N and P fertilization on the ecological success of native bunchgrasses. A complete census of each *Andropogon* or *Sorghastrum* colony was made in each of twelve randomly selected plots, and each bunchgrass colony was individually marked with a forestry flag. The total number of bunchgrass colonies (Bunchgrass Number, colonies per plot) was used as a primary response variable in this analysis. The diameter at soil level of each individual bunchgrass colony was then measured, and the basal area of each colony was calculated. The sum of *Andropogon* + *Sorghastrum* basal area was then calculated for each of the 12 plots, and the proportion of the total area that was occupied at the soil level by these two species in each plot (Percent Bunchgrass Cover) was used as an additional response variable. Statistical analyses of these data were performed with the SYSTAT statistical software (SPSS 2000).

Results and Discussion

Our results revealed a marked effect of phosphorus availability on the response of the two native tallgrass prairie bunchgrasses to a strong nitrogen supply gradient. In the seven subsampled plots that received only manipulations of nitrogen availability (N alone), no significant pattern was evident in the response of prairie grasses to the N supply gradient, either as the number of bunchgrass colonies present, or as percent basal cover (Figure 1). The Percent Bunchgrass Cover for the native tallgrass species never exceeded 13% in these seven plots, and there was no indication that this response variable changed consistently with alterations in the supply of available nitrogen. In contrast, data from the five subsampled plots receiving manipulations of both nitrogen and phosphorus (N+P) revealed a highly significant decrease in both Bunchgrass Number and Percent Bunchgrass Cover of these species along the nitrogen availability gradient (Figure 2). These results strongly suggest that soil phosphorus can mediate the effects of variations in soil N supply on the abundance of these native prairie grasses.

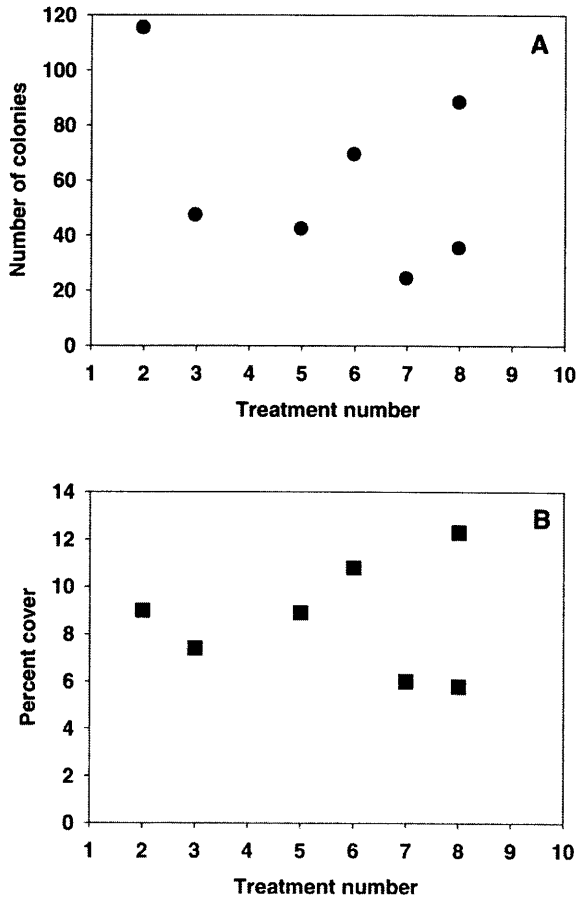


Figure 1. Response of (A) Bunchgrass Number and (B) Bunchgrass Percent Cover to an experimental nitrogen supply gradient in plots receiving nitrogen fertilization alone. The nitrogen supply treatment numbers are 1=D2; 2=D1; 3=C; 4=N1; 5=N2; 6=N3; 7=N4; 8=N5; and 9=N6 (see text). No significant relationship between either response variable and the N supply gradient is evident.

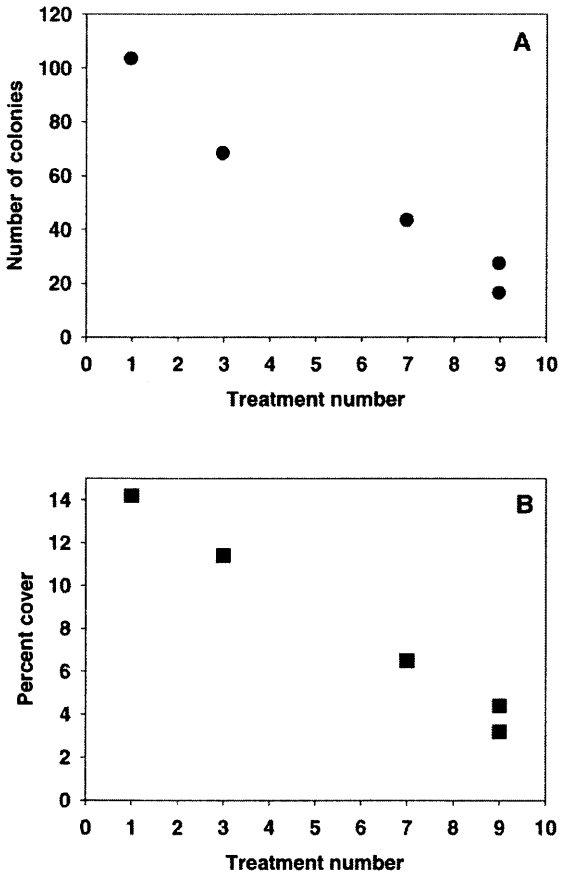


Figure 2. Response of (A) Bunchgrass Number and (B) Bunchgrass Percent Cover to an experimental nitrogen supply gradient in plots receiving both nitrogen and phosphorus fertilization. The nitrogen supply treatment numbers are 1=D2; 2=D1; 3=C; 4=N1; 5=N2; 6=N3; 7=N4; 8=N5; and 9=N6 (see text). Both inverse relationships are highly significant (P < 0.05, Spearman Rank Correlation).

Summary

The tallgrass prairie ecosystem is a highly valued resource in much of the Midwestern portion of North America, but the rate at which highly-diverse tallgrass prairie vegetation can be restored on abandoned farm land is slow at best (Kindscher and Tieszen 1998). Major efforts are thus being made to find methods that accelerate the prairie restoration process (for example, Warkins and Howell 1983; Sperry 1994; Packard and Mutel 1997). Because soil nitrogen availability has been demonstrated to have strong effects on the competitive success of native tallgrass prairie species, maximizing the intensity of nitrogen competition should help to favor the establishment and ecological success of these highly desirable species during the restoration process. For example, the use of organic matter supplements to reduce soil nitrogen availability has been used with success during tallgrass prairie restoration by Morgan (1996).

Measurements of soil N should also be considered in the context of soil phosphorus availability. In the study reported here, soil Bray P measurements suggested that phosphorus could potentially be growth-limiting for some of the plant species that were present in our experimental plots. Similarly, in recent tallgrass prairie restoration effort near Lincoln, Nebraska, Stelling and Stock (2000) also reported low soil P concentrations, suggesting that co-limitation of plant communities by both N and P potentially may occur elsewhere in the Midwest as well. In situations of possible N and P co-limitation, the data from Fig. 1 and Fig. 2 above suggest that small additions of superphosphate fertilizer may greatly enhance the success of native grasses in replanted tallgrass prairies by increasing soil Bray P, thereby intensifying the degree of N-limitation experienced by the plant community. As noted above, C_4 species such as big bluestem (*Andropogon gerardi* Vitman) and Indian grass (*Sorghastrum nutans* (L.) Nash) are competitively favored by strongly N-limited conditions, and thus artificial amendments of some restored prairie tracts with modest quantities of P may result in accelerated rates of succession towards eventual dominance of highly desirable prairie bunchgrasses. This hypothesis should be tested further in additional tallgrass prairie restorations in which the vegetation potentially experiences N and P co-limitation.

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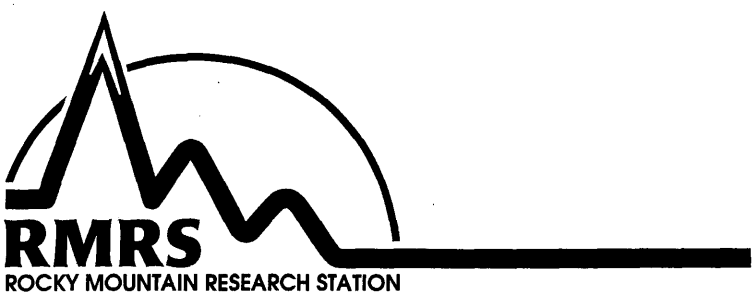
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