Comments

Tree Planters' Notes
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Cover: *Sunset at Skyway Point, Highway 65, Grand Mesa-Uncompaghre-Gunnison National Forests, Colorado (Forest Service photograph by R.E. Grossman, retired, Klamath Falls, Oregon).*

Certified Seed and Artificial Forest Regeneration

Little use has been made of the schemes for certifying the genetic identity of forest reproductive material over the many decades since the schemes were first made available. Now, however, changing patterns in the forest seed market and public opinion might well change this situation and certification thus become more the rule than the exception. Nursery and tree improvement workers as well as land managers need to take a second look at the need for seed and seedling certification to prepare for a changing future.

Artificial forest regeneration has been practice in the United States for most of the 20th century. Foresters began planting trees during the first decade of this century. As the science of genetics was rediscovered and developed in the 1930's and 40's, foresters too became aware of the importance of genetics in the success of their work. As some plantings of seedlings grown from improper source materials failed, it became clear that only trees with adapted genotypes should be planted.

Systems were established in agriculture to certify the adaptability of the many new varieties that were coming on the market. Farmers were besieged with many choices of new varieties and the crop improvement agencies were established by state governments, mostly in the 1950's, to assist farmers. The crop improvement agencies used agricultural experiment station tests and other scientific tests to determine which varieties should be certified as good choices for farmers in their respective state. Now, farmers only need to look for the blue tag to assure themselves that they are planting improved species and varieties that are appropriate for their area and conditions.

These systems made sense to foresters also, and standards for the production of certified tree seed were adopted. Three classes of seed came to be recognized: source identified, phenotypically superior, and genetically proven superior. The systems were eventually extended to seedlings because it is the seedlings that are usually planted in the forest, not the seeds. Unfortunately, by in large, these carefully written schemes gathered dust and were not widely applied. It is my opinion that this happened because the producers of the seed were often also the users of the seed and because the number of buyers and sellers was small. Everybody knew everybody and, although some abuses occurred, the opportunity for a fast deal was limited. There was no clearly defined consumer group in need of protection. One major exception was the export of seed from the Pacific Northwest to Western Europe. In this market the buyers of the seed required assurance that they were getting what they paid for and many thousands of pounds of certified-to-source seed from the Pacific Northwest have been exported to the United Kingdom, France, Germany, and other European countries.

As we enter the second century of scientific forest management in the United States, some new developments are signaling a possible change in certification practices for forest reproductive materials. First, there is a dramatic increase in the amount of forest seed being traded. The 1979 USDA Forest Service booklet "Seed and Planting Stock Dealers" listed 30 sellers and 168 species for sale. The soon-to-be-released Forest Service publication,

"Commercial Suppliers of Tree and Shrub Seed in the United States," lists 58 sellers of seed and over 1800 species-a dramatic increase. In June 1995, 1 was invited to attend an organizing meeting of the Tree, Shrub, and Native Species Group of the American Seed Trade Association. This group was being organized at the request of some of the established and conscientious dealers who believe that the market has become too chaotic. As they try to offer source-identified materials to buyers, they report being undercut by new dealers who are not paying attention to source and quality as would be appropriate for good conservation. These dealers believe that a system to assure quality and to educate buyers and sellers is strongly needed for both seeds and seedlings.

Second, there is a much wider interest from the general public in what is practiced on forest lands. There are well-organized "publics" that now believe that they have a right and an obligation to speak out on the management of public and private lands. These publics often have an effective voice in the debates on forest land management. Therefore, it would behoove land managers to always document their work with good technical records. In some circles, the very idea of planting wild plants (as opposed to allowing "natural" regeneration) is viewed as harmful because it is not a "natural" process. The documentation of the process of seed collection, conditioning, and seedling production by a third party through seed certification is a powerful way to document that the practice of artificial regeneration is not harmful.

Quality assurance standards are now being applied in the production of many items in our modern world. When the initials ISO appear on a product, it means that the item was produced following quality assurance protocols outlined by the International Standards Organization. Use of a widely recognized protocol such as seed certification would help the forestry community gain credibility and would also help to educate the public, new nursery personnel, and new seed dealers of the importance of proper seed sources and good seed quality. A certification tag on a bundle of seedlings should cost as little as 50 to 75 cents. Therefore, the operational cost of certification is small but can pay big dividends in protecting the resource and demonstrating that environmentally sound forest regeneration is being practiced. Seed and seedling certification is a procedure that needs to be adopted by all who buy and sell forest reproductive materials. It should become an integral part of artificial regeneration in the upcoming second century of artificial reforestation.

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Missoula Technology and Development Center's 1995 Nursery and Reforestation Programs

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The USDA Forest Service's Missoula Technology and Development Center (MTDC) evaluates existing technology and develops new technology to ensure that nursery and reforestation managers have appropriate equipment, materials, and techniques for accomplishing their tasks. Work underway in 1995 is described and recent publications, journal articles, and drawings are listed. Tree Planters' Notes 46(2):36-45; 1995.

The Missoula Technology and Development Center (MTDC) has provided improved equipment, techniques, and materials for Forest Service nurseries and reforestation programs for more than 20 years. The Center has worked to improve efficiency and safety in these areas, and throughout the Forest Service. The Center evaluates existing technology and equipment and develops new technology and equipment. Projects are funded by the USDA Forest Service's Washington Office Timber Management Staff. The Center's program of work in nurseries and reforestation is selected by the National Forest Regeneration Committee, which is made up of representatives from various levels of the Forest Service. The following summaries describe the Center's current projects.

Nursery Projects

Nursery technical services (project leader-Ben Lowman). This continuing project allows MTDC to provide technical services to Forest Service nurseries and to respond to requests from state agencies and private individuals. New technology is continually monitored under this project. Center personnel disseminate this information by presenting papers at professional meetings and symposiums. The Center also answers inquiries from field personnel, visits various Forest Service nurseries, and provides drawings and publications on request.

The Center personnel attended the Western Nursery Conference in Moscow, Idaho, visited the Georgia Forestry Commission to view modifications to the acorn planter, and presented a summary of MTDC work at the Great Plains Reforestation Workshop in Nebraska during fiscal year 1994.

Your nursery project proposals are welcome. They should be submitted to Ben Lowman in writing or over the DG (B.Lowman:RO1A). Write a summary that clearly states the problem and proposes your desired action. The information is used to determine priorities, to link you with others with similar problems or with solutions to your problem, or to establish a project to solve the problem with appropriate equipment or techniques.

Pollen equipment (project leader-Debbie O'Rourke). Thirty years ago the Forest Service launched an expanded tree improvement program. A network of seed orchards with genetically superior trees was created in an effort to produce top-quality seed. These trees are now in the cone-bearing stage. Protecting the genetic quality of their seed is of prime importance.

Stands of timber surrounding Federal orchards produce "inferior" pollen that can threaten the decades of work done by tree breeders to upgrade seed quality. About 40% of the tree seed now produced by these orchards is the result of fertilization by outside, "inferior" pollen. Equipment and methods to control orchard pollination are essential to the seed improvement program.

The Center has been working with orchard personnel and Forest Service Research units to develop equipment for mass collection and mass application of pollen. A vacuum collection system developed by the Center gives orchard managers a means of collecting a large supply of pollen from the crowns of designated trees in a quick and efficient manner. This pollen is cleaned and stored for future application to target trees during their receptive period.

For application, the Center has developed a modified tractor-mounted air duster that can blow the collected pollen high into the crown of orchard trees. Dry pollen application was tried first, but "blow-by" was very high. Subsequent tests used pollen in water suspension. Monitoring of the effectiveness of this method will be completed by Don Copes, USDA Forest Service, Pacific Northwest Research Station, this year.

This equipment can help protect the quality of seed and increase orchard productivity by ensuring that an

adequate amount of genetically acceptable pollen is available. Systems for both West Coast Douglas-fir and North Carolina loblolly pine have been developed. A final report, complete with drawings and specifications, is being prepared (figures 1 and 2).

Native plant seed collector (project leader– Debbie O'Rourke). As part of the Forest Service's shift into ecosystem management, land managers are paying more attention to plant diversity. Management plans focus on all plants on a site, not just the commercial tree species. Shrubs and non-commercial trees will be part of the planning package. Because of the previous emphasis on commercial tree species, little work has been devoted to the techniques and equipment necessary for collecting various native plant seeds. This project will determine the needs in this area and find equipment or methods to meet these needs.

The Center is surveying Forest Service personnel to determine what equipment is needed to adequately collect plant seed from native shrubs and non-commercial species. MTDC will also conduct a market and literature search. Results will be reported to the Forest Regeneration Committee.

People in tree tops (project leader— Tony Jasumback). For many years equipment has been needed to gain access to the tops of trees for various cultural work such as pollination, cone collection, and insect and disease surveys. Tree climbing equipment is commonly used, but it is dangerous and provides only limited access to the entire crown.

Mechanical equipment such as lifts require frequent moving to reach all sections of a tree and are limited in the heights they can reach. The Center conducted a search of new commercial technology and determined

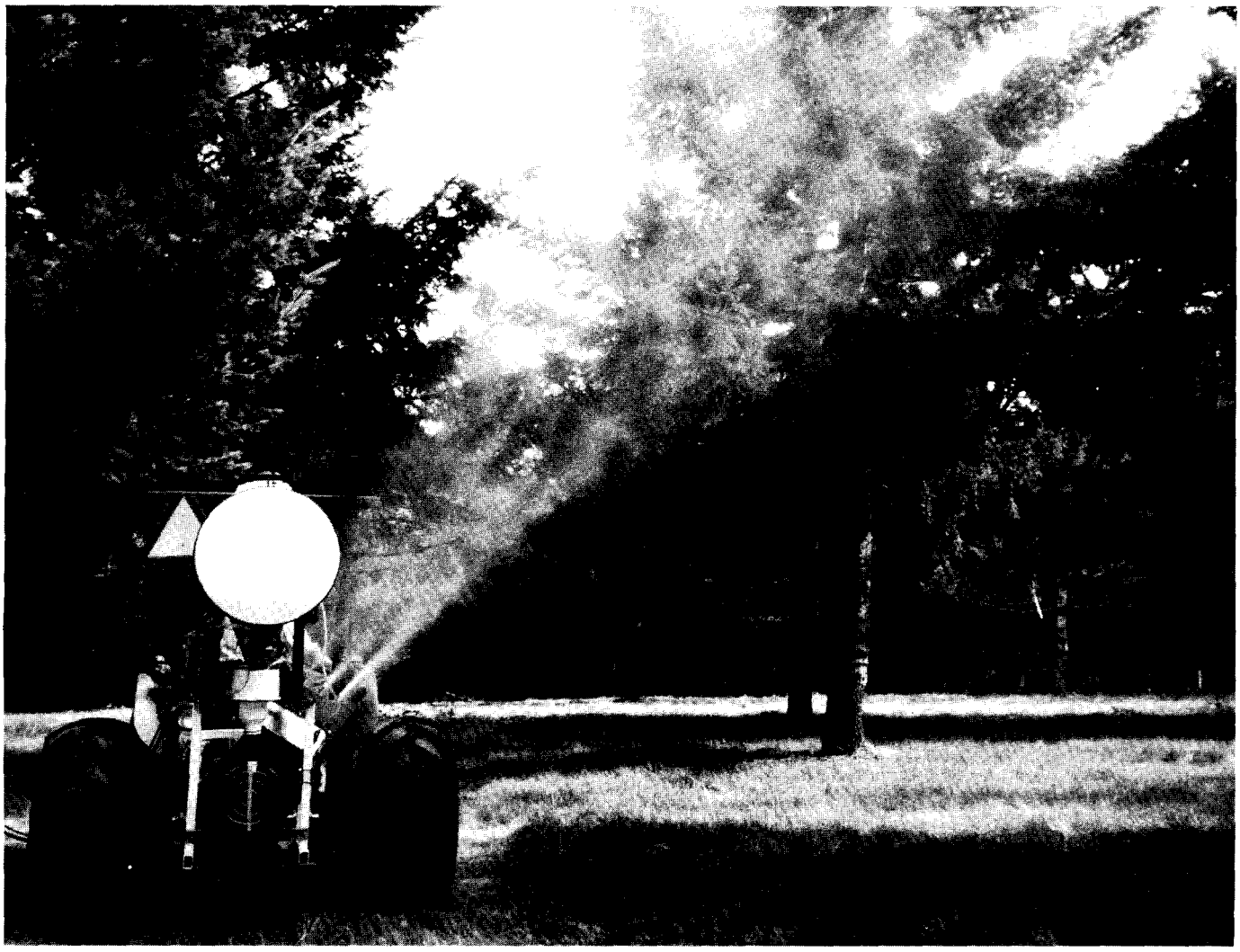

Figure 1—*Wet pollen applicator.*

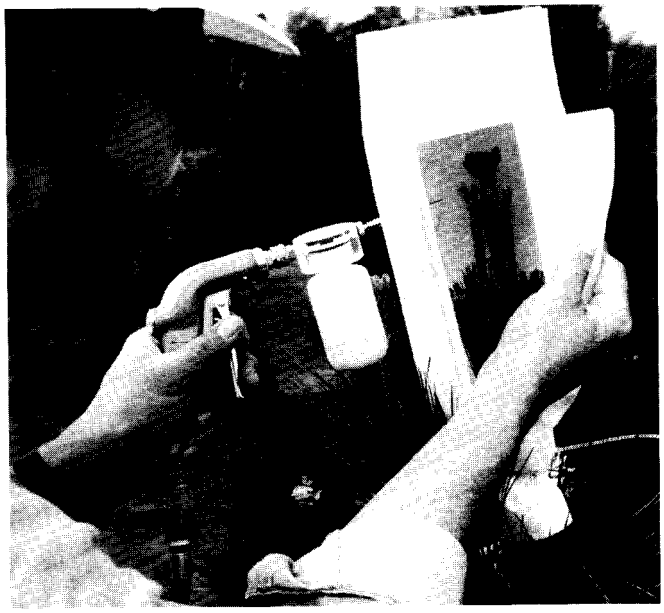

Figure 2—*A poly-mix applicator that applies a mixture of pollen from superior trees.*

that equipment already existed to meet Forest Service needs. The results were published in Tech Tip 9424-2314-MTDC, "Aerial Lifts for Working in Tree Tops," and the project is now closed.

Nursery soil fumigation (project leader— Dick Karsky). Growth of young trees is affected by the levels of pathogenic organisms present in the nursery environment. Certain cultural practices, such as crop rotation, have been used to reduce these levels in nursery seedling beds, but chemical application has been the preferred method. Dazomet (basamid) and methyl bromide were two fumigants used to sterilize beds in the past.

Methyl bromide has been found to be environmentally harmful and the U.S. Environmental Protection Agency will ban its use in 5 years. MTDC was asked to find an economically and environmentally acceptable way of sterilizing nursery bed soils. Both microwave and steam sterilization methods will be investigated. A cooperative agreement or contract will be arranged to determine the feasibility of microwave technology.

The Center has acquired a portable diesel-fired steam generator and will configure it for nursery operations. The Center is working with Bob James (a plant pathologist with the USDA Forest Service's Northern Region) and the Coeur d'Alene Nursery to develop a test plan for the steam sterilization machine. Preliminary testing will take place at the Coeur d'Alene Nursery and results will be reported.

Root pruner (project leader— Debbie O'Rourke). During seeding, grading, and packing operations at forest tree nurseries, seedlings are pruned in the packing shed to provide seedlings with a uniform root length. This is currently done by hand with paper cutters similar to those found in many offices. This system has a number of problems. Hand cutting is difficult. Workers tire quickly and are subject to injuries such as carpel tunnel syndrome and finger lacerations. The work is slow and typically requires additional personnel and equipment to keep up with production. Finally, contractors have difficulty meeting Forest Service root length specifications.

The Center was asked to develop a root pruner to automate the pruning process and increase packing shed safety and efficiency. The prototype accommodates up to an 8-inch-diameter seedling bundle, carrying it to the cutting area on a plastic conveyor chain. When these bundles enter the cutting area, the shear is activated and the seedlings are pruned to the correct length. The bundles are transported to the end of the unit and packed in boxes. The cutting area is completely enclosed with a Lexan guard, which provides a barrier between the operator and the cutting mechanism, yet still allows the necessary visibility. The system has been refined based on field tests. Fabrication drawings and a report will be prepared terminating the project (figure 3).

Machine vision (project leader— Dave Gasvoda). Forest Service tree nurseries tailor their seedlings to specific needs requested by nation forests and ranger districts. To do so, these nurseries must have an effective quality control system. Currently, lifted seedlings are delivered to packing sheds for grading and packing. Graders sort seedlings by hand, cull the unacceptable plants, and sort the others by stem diameter, top length, root area, and overall quality. They place the acceptable seedlings on a packing belt for final processing and packaging. Quality control checkers monitor this operation, picking samples and overseeing grader performance. This process is labor intensive and expensive. The Center was asked to automate the quality control and grading in an effort to reduce these costs.

Under contract to MTDC, Glenn Kranzler and Michael Rigney at Oklahoma State University delivered a machine vision quality control inspection station to the Forest Service's J. Herbert Stone Nursery (Central Point, Oregon) in February 1994. The system utilizes high-resolution line-scan camera technology and a personal computer. Ten tree seedling morphological features are measured at rates of up to 10

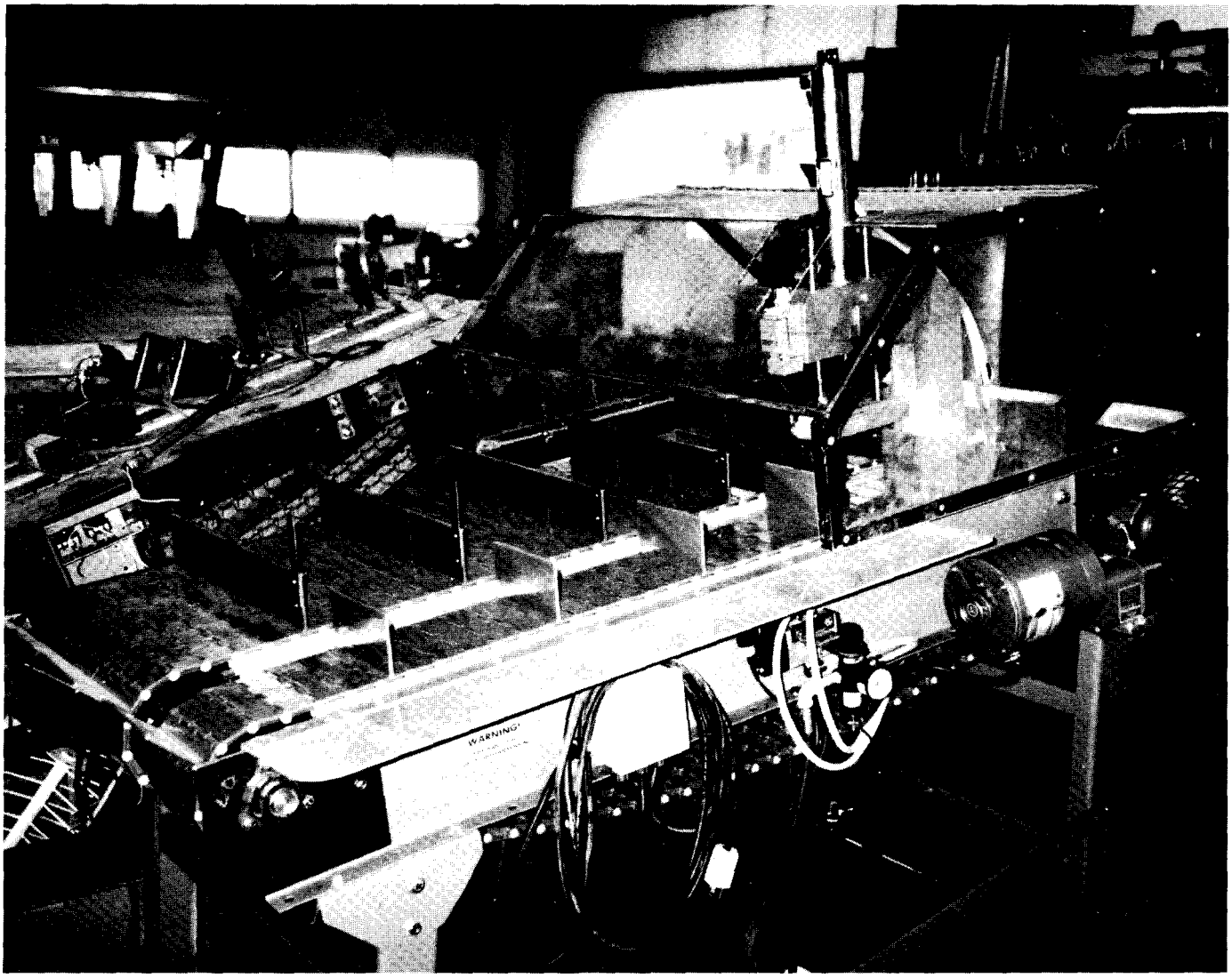

Figure 3—*The MTDC root pruner.*

seedlings per second. Initial performance tests demonstrated measurement precision equal to or greater than manual measurements.

The seedling inspection station can be expanded to automate grading in the production line. Several related aspects of defect detection and seedling handling still must be addressed to achieve a comprehensive automated system.

Investigation of color detection of defects such as chlorotic foliage and stripped root laterals showed promising results. A positioning and sorting mechanism for handling the seedlings after grading was found to be marginally suitable to support automated root pruning.

During fiscal year 1995, MTDC will continue to work with OSU to develop a fully functional automatic grading system. The problem of seedling sorting and handling after grading will be more completely examined. Progress will continue to reported under a new project-seedling grading machine (figure 4).

Smart toolbar (project leader— Dick Karsky). Nursery equipment operators have experienced problems in maintaining toolbar height at a consistent level above the seedbed during various cultural operations. This capability is essential for such tasks as root wrenching, root culturing, and top pruning.

With current technology, a system can be designed to automatically sense toolbar height and manipulate the tool to maintain that height. MTDC is working with Forest Service nursery personnel to perfect such a system. Essentially, this project tested various distance-sensing devices, determined the most applicable,

Figure 4—*Machine vision quality control inspection station for tree seedlings.*

and designed a system for automatic height control.

Both mechanical ground sensors and ultrasonic devices have undergone preliminary tests. The ultrasonic sensor seems most promising. However, for lateral control, the mechanical sensor is still necessary. A prototype smart toolbar was evaluated at the Coeur d'Alene nursery in 1995 and results will be reported.

Reforestation Projects

Reforestation technical services (project leader—Ben Lowman). Through this continuing project, Center personnel provide a variety of services to field units. Surveys are conducted to determine current reforestation field problems. Those problems are translated into projects in the reforestation program. The Reforestation Technical Services Project allows us to investigate promising new techniques and equipment that may, after evaluation, become part of the Forest Service inventory of equipment. In addition, the project provides a forum for answering inquiries from field personnel concerning equipment, material, and techniques applicable to reforestation activities. Papers presented at professional meetings, technical reports, and drawings are also funded through this project. Current work includes:

- Adaptation of a Pacific Northwest Region tree climbing guide into a Forest Service-wide guide. The guide was made available in the fall of 1995.
- Modification of the Salmon blade. The drawings were updated and sent to interested commercial manufacturers, including Weldco-Beales, for commercial production.
- Production of a video on natural regeneration and timber stand release with Doug Basford, USDA Forest Service, Northern Region. Loan copies are available from MTDC.

- Completion of work on the loblolly tree seed collection system and the power platform. Reports were published to close out these projects.
- Responded to numerous field inquiries for information on tree girdlers, feller bunchers, and excavators.

Center representatives meet with the Forest Service's National Forest Regeneration Committee each year to review the status of ongoing projects and new projects. Project proposals are welcome. They may be submitted to Ben Lowman at MTDC. Write a summary of the problem and the desired action. The information will be used to determine priorities, and to link you with others with similar problems or to those who may have solutions to your problem.

Animal repellents (project leader— Debbie O'Rourke). The survival and growth of seedlings planted on National Forest System lands has improved dramatically in the past 20 years, primarily because better quality seedlings are being produced in federal nurseries and because increased care is being used in planting and handling these seedlings. One major problem remains—animal predation of planted stock.

Although livestock, rodents, and other animals take their toll, deer and elk are the primary browsers. By nipping off buds and shoots, elk and deer restrict the growth of some seedlings and kill others. Fencing can reduce this damage, but it is expensive and impractical in most field situations. Chemical sprays, powders, and systemics have been tried for years with only limited success.

The Center has teamed with the USDA Animal and Plant Health Inspection Service (APHIS) under a cooperative agreement covering animal pest control research. In 1993 a steering committee including representatives from the Center, APHIS, and the USDA Forest Service's Pacific Southwest and Pacific Northwest Regions was formed to outline the project's objectives. The steering committee decided that APHIS and MTDC should enter into a contract covering three services: testing repellents and barriers on penned animals; publishing a comprehensive catalog of currently available animal repellents and barriers; and publishing a Tech Tip reporting the results of a field evaluation of repellents intended to keep animals away from certain areas. The tests have been completed and the catalog and Tech Tip were published. Another Tech Tip from MTDC on pocket gophers and gopher control based on a comprehensive report written by Ron Bonar is now available.

Seedling protection (project leader— Keith Windell). MTDC has been working with the USDA Forest Service's Southern Region timber management to evaluate commercially available devices that can to protect seedlings from animal damage and promote growth. Seedling protectors have been successfully used in Europe and in some areas of the United States for years. Along with protecting the young plant from animal browsing, these devices can create a microclimate around the seedling that will improve survival and promote its early growth (figure 5).

The Center conducted an extensive literature search to see what previous work had been done in this field. Results of that search were reported in "Tree Shelter Survey Results" (Proj. Rep. 9424-2822-MTDC). Tech Tip 9324-2315-MTDC, "Tree Shelters for Seedling Survival and Growth," summarized information published in the larger report and listed new shelter designs and information on manufacturers and distributors. A fact-finding trip to England allowed the center to monitor shelter development there and discuss current uses of the shelters. The findings were summarized in "Seedling Protection in England (Proj. Rep. 9324-2845-MTDC).

MTDC assisted at the National Tree Shelter Workshop held in June at Harrisburg, Pennsylvania. Center personnel discussed the durability of tree shelter materials. Jim McConnell, who retired from the Southern Region Timber Management Staff; Jim Barnett, project leader at the Southern Research Station; and Dave Haywood, research forester at the Southern Research Station, are helping to guide this project.

Mulch for seedlings (project leader— Keith Windell). Ground mulch is commonly used in the ornamental and landscape business to reduce vegeta-

Figure 5—*Deer and elk nip off buds and shoots from unprotected seedlings.*

tive competition and improve soil moisture around newly planted trees and shrubs. Forest Service researchers determined that ground mulch could significantly improve seedling survival and promote early growth.

As part of a nationwide cooperative research effort, MTDC collected data on various types of mulch material and current techniques and equipment used to place the material around newly planted trees. The Center has also helped collect the final data on a cooperative mulch test project with the Lolo National Forest.

Results will be published in an MTDC report intended to serve as a reference for field foresters. The report will include information on commercial mulches currently available, suggested installation techniques, a quick overview of the results of past mulch studies and of the cooperative mulch test, recommendations, and a comprehensive bibliography. Forest Service employees from the Southern Research Station, the Forest Products Laboratory, Pacific Northwest Region, and Northern Region are cooperating with the project (figure 6).

Stump applicator for feller-bunchers (project Leader— Dick Karsky). MTDC has designed and fabricated a tank and spray system that can be attached to feller-buncher tree harvesters for applying stump treatments during thinning operations. This system will be used to prevent annosum root rot in thinned conifer stands.

Heterobasidion annosum is the most important disease of thinned pine plantations in the Southern Region. Thinning opens a stand to colonization by *H. annosum* through the freshly cut stump surfaces. The fungus spreads to adjacent trees through root grafts. Treating stump surfaces with a solution of TIM-BOR™ or a solution of the competing fungus *Phlebia gigantia* can control this disease. However, stump application by hand is labor-intensive. The MTDC system allows the feller-buncher operator to treat the stump when it is cut.

The system consists of a 40-gallon tank, a diaphragm pump, a timer, and a full-cone nozzle. The nozzle is mounted behind the saw head where it can be seen by the operator and still be protected from debris. A 3-second spray burst fully covers a stump.

The prototype system was tested at the Savannah River Forest Station in September 1994. The unit proved to be a practical, easily attached stump applicator system. It can easily be adapted to different models of feller-buncher harvesters. Minor improvements incorporated into the prototype design will be tested at Savannah River in 1995. Results of the test will be reported.

Spot site pre-mixing (project leader— Dick Karsky). Most site preparation equipment developed for forest applications has been designed with a scalping action. Scalping moves much of the topsoil to the side of the planting spot or casts it even farther away. Foresters wanted better techniques that allowed the soil treated in spot site preparation to be left in the spot.

This requires a mixing action rather than a scalping movement. This technique is frequently used in agriculture and nursery work to cultivate and rotary-till. However, rocky soils in forestry applications have made mixing difficult. This project's goal is to provide equipment to Forest Service reforestation personnel that will enable them to prepare planting sites by mixing rather than scalping.

The Center contacted personnel from the Francis Marion National Forest in South Carolina (Southern Region) to define the problem and establish requirements for a mixing action site preparation machine. The Center will contact other regions and conduct a literature and equipment search to determine if existing products meet these needs.

Steep slope site preparation (project leader— Dick Karsky). Mechanical site preparation is generally restricted to slopes of less than 35%. With the emphasis on ecosystem management in the Forest Service, more residual material is being left after timber harvests. New methods are needed to adequately treat brush and logging debris and to prepare planting sites on slopes steeper than 35% with heavy slash.

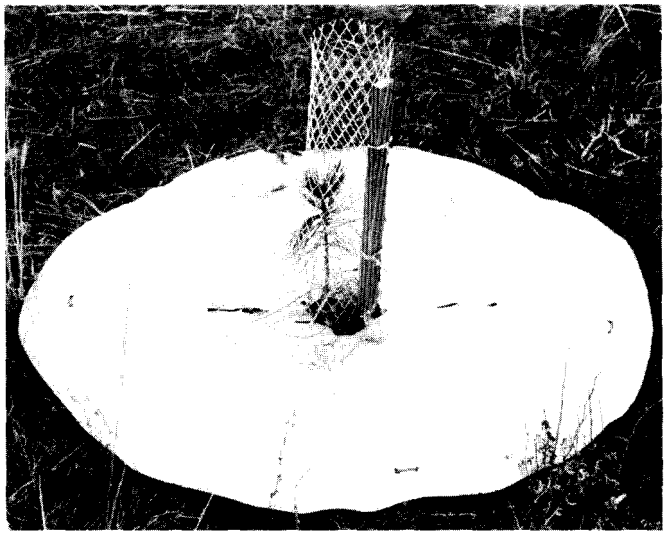

Figure 6—*Mulch mat.*

The Center conducted a market and literature search to seek equipment and techniques available for work on steep slopes. All applicable equipment— from large excavators to small four-wheel-drive ATV's— was considered. Results of the MTDC investigation revealed a variety of equipment that would meet Forest Service needs. The report, "Site Preparation Equipment for Steep Slopes" (Proj. Rep. 9224-2839-MTDC), was published and the project is closed.

Hawk scarifier (project leader— Keith Windell). This project will develop a safer digging head for a commercially available multiple-use chainsaw attachment. This attachment can be used for scarifying tree planting sites, clearing fire lines, and constructing trails. The Center is developing an alternative digging head that will do all these tasks and be safer to use than the currently available commercial design. An electrically powered test stand was constructed to simulate a gasoline chainsaw.

Several prototypes have been fabricated and tested. Additional field tests are planned for fiscal year 1996. Safety is the primary concern at this time (figure 7).

Small-area forestry equipment (project leaders— Bill Kilroy and Keith Windell). In this project, MTDC will determine the needs of field personnel for small-area forestry equipment. During fiscal year 1995, initial contacts have been made and site visits arranged. After determining what is needed in small-area operations, the Center will make an extensive market search to identify commercially available equipment that fills these needs. A catalog of this equipment and appropriate sources will be published, along with recommendations of further work to be presented to the Forest Service's Regeneration Steering Committee.

Figure 7—*Hawk scarifier.*

Cruiser's gear carrier (project leader— George Jackson). Forest Service timber cruisers are faced with the problem of carrying an increasing amount of equipment in the woods to do their job. In addition to the traditional gear, timber cruisers now may carry GPS satellite navigation receivers, laser tree measuring devices, electronic calculators, and recording devices. MTDC has designed a vest that efficiently carries this array of bulky equipment without restricting freedom of movement. It also distributes the load to minimize fatigue.

The cruiser's gear-carrying system consists of a vest constructed of 9-oz (per square yard) nylon mesh. The equipment pockets are constructed of 11-oz backcoated nylon duck. These pockets are sized to fit specific cruising gear and instruments such as Relaskop, clinometer, compass, flagging tape, and D tape. The vest has breathable padding in the shoulder and back area and a large zippered back pocket accessible from either the right or left side. The system is designed so that quart paint cans and other bulky items can be carried in a detachable leak-resistant backpack.

The cruiser's gear-carrying system has been designed to allow the user to comfortably carry a large amount of equipment. The vests are durable and provide a long service life. They will be available in four sizes (small, medium, large, and extra large).

The Center has completed the procurement package, and the drawings and specifications have been forwarded to the General Services Administration for procurement. The cruiser's gear carrying system should be available from the General Services Administration by November 1995. A Tech Tip will be published (figure 8).

Pruning equipment (project leader— Keith Windell). The Center is beginning a project to determine what pruning equipment currently available is best for timber stand improvement. MTDC has surveyed field personnel for current methods and equipment used. Results are available in an MTDC publication. Researchers were contacted to determine the best and most efficient pruning methods. The Center purchased equipment for a comprehensive field evaluation. Field testing is underway in the USDA Forest Service's Pacific Northwest Region.

Figure 8—Cruiser gear-carrying system.

Field coordinate locator (project leader— Tony Jasumback). The Forest Service is continuing to incorporate global positioning system (GPS) technology into resource management tasks. MTDC supports this effort and serves as a clearinghouse for information, training, and acquisition of appropriate technology. The Center, in conjunction with the University of Montana, schedules GPS training courses designed for land managers, tests new products under forest canopy conditions, and holds a communications security account. As a result, MTDC can offer Forest Service personnel autonomous operation, realtime availability. Units will be able to order the military's Precision Lightweight GPS Receiver for use in land management operations. In recent tests at the Lubrecht GPS test range, this receiver provided navigational information to a way point with an average horizontal error of only 8 meters. This is in autonomous operation without a differential station. MTDC will be the keying facility for these receivers. Publications and a video on GPS operation and technology as it applies to land management are available from MTDC.

Recent MTDC Publications

Gasvoda D. 1993. Automated seedling height measurement. Proj. Rep. 9324-2810-MTDC. Missoula, MT: USDA Forest Service, MTDC.

Gasvoda D. 1994. Machine vision— a computerized sorting and grading system for tree seedlings. Tech Tip 9424-2319-MTDC. Missoula, MT: USDA Forest Service, MTDC.

Hallman R. 1993. Net retrieval tree seed collection system. Tech Tip 9324-2325-MTDC. Missoula, MT: USDA Forest Service, MTDC.

Hallman R. 1993. Reforestation equipment catalog. Proj. Rep. 9324-2837-MTDC. Missoula, MT: USDA Forest Service, MTDC.

Hallman R, Jasumback A. 1993. GPS training project— Indonesia. Proj. Rep. 9324-2848-MTDC. Missoula, MT: USDA Forest Service, MTDC.

Herzberg D. 1992. Mobile tree seedling coolers. Proj. Rep. 9324-2811-MTDC. Missoula, MT: USDA Forest Service, MTDC.

Jasumback A. 1993. Evaluating the GPS receiver under a dense tree canopy. Proj. Rep. 9324-2319-MTDC. Missoula, MT: USDA Forest Service, MTDC.

Jasumback A. 1993. Trimble Ensign GPS Receiver. Tech Tip 9324-2321-MTDC. Missoula, MT: USDA Forest Service, MTDC.
Jasumback A. 1994. Aerial lifts for working in tree tops. Tech Tip 9424-2314-MTDC. Missoula, MT: USDA Forest Service, MTDC.
Jasumback A. 1994. GPS Use survey results. Proj. Rep. 9424-2824-MTDC. Missoula, MT: USDA Forest Service, MTDC.
Karsky D. 1993. Site preparation equipment for steep slopes. Proj. Rep. 9324-2804-MTDC. Missoula, MT: USDA Forest Service, MTDC.
Karsky D. 1993. Chunkwood roads. Proj. Rep. 9324-2327-MTDC. Missoula, MT: USDA Forest Service, MTDC.
Karsky D. 1994. Excavators for site preparation. Tech Tip 9424-2310-MTDC. Missoula, MT: USDA Forest Service, MTDC.
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Lowman B, and others. 1992. Bareroot nursery equipment catalog. Proj. Rep. 92242839-MTDC. Missoula, MT: USDA Forest Service, MTDC.
Windell K. 1993. Tree shelters for seedling survival and growth. Tech Tip 9324-2315-MTDC. Missoula, MT: USDA Forest Service, MTDC.
Windell K. 1993. Mulches for increased seedling survival and growth. Proj. Rep. 9324-2820-MTDC. Missoula, MT: USDA Forest Service, MTDC.
Windell K. 1993. Mulch evaluation project. Tech Tip 9324-2343-MTDC. Missoula, MT: USDA Forest Service, MTDC.
Windell K. 1993. Seedling protection in England. Proj. Rep. 9324-2845-MTDC. Missoula, MT: USDA Forest Service, MTDC.
Windell K. 1994. MTDC pruning equipment survey results. Proj. Rep. 9424-2817-MTDC. Missoula, MT: USDA Forest Service, MTDC.
Windell K. 1994. Tree shelter survey results. Proj. Rep. 9424-2822-MTDC. Missoula, MT: USDA Forest Service, MTDC.
Windell K. 1994. Power platform. Proj. Rep. 9424-2830-MTDC. Missoula, MT: USDA Forest Service, MTDC.

Recent Drawings
Orchard Seed Harvester— MTDC 851
Pollen Collector Head— MTDC 856
Progeny Seeder— MTDC 858
110-V AC Field Storage Unit— MTDC 865
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Trees Grow Better With Water

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Seedlings of shining gum, Eucalyptus nitens *[(Deane and Maiden) Maiden] were field planted during early summer near Christchurch, New Zealand. Half of the seedlings received 200 ml of water containing nutrients (Peters Excel at 2 g/l), applied to the soil surface around the root collar after planting. The other half received no treatment. Differences in height growth were readily apparent within 1 month and continued for the rest of the trial. Twenty-five percent of the unwatered plants died within 1 month, whereas 100% of the watered plants remained alive. The marginal increase in cost of applying water to seedlings immediately after planting should be easily justified in terms of improved seedling establishment and subsequent growth.* Tree Planters' Notes 46(2):46-47; 1995.

The success of plantation establishment is frequently measured in terms of survival. Rarely is the rate of growth considered, other than in a more general sense when comparing species and site growth potential ranking. In New Zealand, bareroot seedlings are the traditional planting stock, planted out during the wetter part of the year in winter and early spring (Revell 1982). Changing to containerized stock allows greater flexibility in terms of planting period (Faulds and van Dorsser 1979, Barnett and Brissette 1986).

Application of water after planting is commonly used to improve plant establishment under particularly harsh conditions (Rodgers 1994). Volumes in excess of 1 liter per plant have been suggested (Bainbridge and others 1993, Haigh 1993). Evidence from vegetable seedling trials indicates that simply ensuring a saturated root plug at time of planting is the most important aspect to rapid root growth from the root plug after planting (Kratky and others 1980). This can be done by saturating the root plug immediately before planting (Nelson 1994) or applying sufficient water to the upper soil profile to saturate the root plug after planting (Cox 1984). Neither practice would be considered practical in a normal plantation context, but a directed application of a small volume of water, just sufficient to saturate the root plug and achieve hydraulic contact with the surrounding soil, is potentially feasible.

This trial was established to determine whether a small volume of water applied after planting would have a beneficial impact on plant survival and growth. Planting in summer was chosen as this is the driest time of year in the mid-Canterbury Plain.

Materials and Methods

Seedlings of *Eucalyptus nitens* were grown in Plantek 63F side-slotted plastic containers (Lannen Plant Systems, Finland) using a commercial blend of peat and pumice containing 6-month Osmocote® granules. Plants were watered as necessary during growth. Planting occurred in early December 1994 into rip lines within spot-sprayed planting positions along a straight north/south fence line. The site, a Lismore Stony soil on an alluvial-derived flood plain, is 15 km south of Christchurch, New Zealand. The upper layer of the soil was completely dry, but soil showed signs of moisture within 100 mm of the surface. Plants were in the size range of 12 to 18 cm tall and 3- to 4-mm collar diameter, allocated randomly to the planting positions.

Alternate seedlings were treated after planting by pouring 200 ml of water containing nutrients (2 g/1 Peters Excel®) onto the root collar area. The other seedlings received no supplemental water or nutrients. No attempt was made to separate the nutrient effect, because the additional cost of having some nutrient in the water would be negligible compared to the cost of watering plants after field planting.

Individual plants were monitored and height growth measured monthly. Height data were analysed by F-test (analysis of variance with variable number of replicates to eliminate plots where plants had died), n = 16 for each treatment, using single plant replicates.

Results and Discussion

The Canterbury Plains are generally dry in summer, but this particular summer was unusually hot and dry. Very little precipitation fell during the first 4 months after planting. Rainfall for the months October 1994 to May 1995 was 20, 22, 24, 32, 25, 32, 30, and 39 mm, respectively.

One month from planting, both growth and survival differences were apparent. Unwatered seedlings were showing obvious signs of water stress, such as wilted leaves, shoot dieback, and 25% mortality. Watered plants suffered no mortality and obvious height growth had occurred.

Subsequent measurements show that, while all plants grew during the period, watered plants maintained their lead in absolute height growth and showed 30% more growth from month 2 (figure 1).

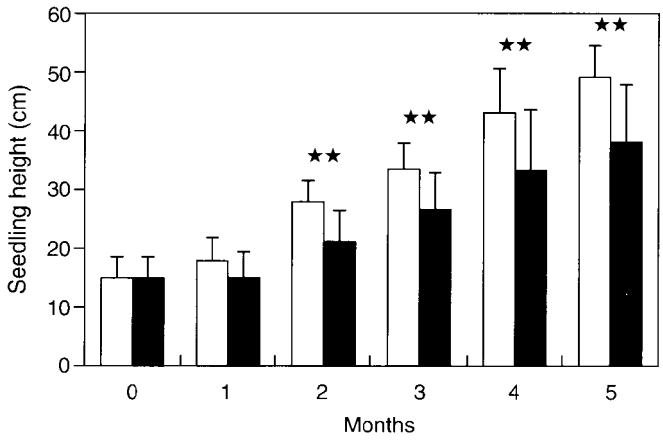

Figure 1— *Height growth of* Eucalyptus nitens *seedlings planted in summer and treated with 200 ml water applied to the root collar after planting , or no treatment ■. The standard error is indicated for each bar. The asterisks indicate treatment effects that are significantly different (F-test, α = 0.01).*

Differences between treatments for months 2 through 5 were significantly different (" = 0.01). Untreated plants were not only generally shorter but were also more variable in their growth.

These data indicate the importance of rapid root establishment from the root plug into the surrounding soil to achieve a high survival rate, as well as early gains in growth. The earlier height growth of the treated plants and subsequent continued lead in plant size is anticipated from other trials in which larger seedlings at planting maintain their advantage, even years later (Simpson 1994).

A longer term trial, and especially covering more planting times, sites, and species, is required to fully evaluate the costs and benefits of seedling watering. The growth differential shown by this trial suggests a highly positive economic impact.

Conclusions

Application of even a small amount of water to seedlings immediately after planting has a profound beneficial impact on both survival and early resumption of growth after planting. The marginal increase in cost of applying water to seedlings immediately after planting should be easily justified in terms of improved seedling establishment and subsequent growth.

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Botrytis cinerea Carried by Adult Fungus Gnats (Diptera: Sciaridae) in Container Nurseries

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Gray mold (Botrytis cinerea Pers. ex Nocca. & Balb.) was the most frequently isolated pathogen cultured from external portions of adult fungus gnats— Bradysia *spp. (Diptera: Sciaridae)— within greenhouses used to grow conifer seedlings in Idaho. Gnats were either collected from open water containers or standard yellow sticky traps. Characteristics and impact of fungus gnat infestations in greenhouses and control procedures for fungus gnats and* B. cinerea *are discussed.* Tree Planters' Notes 46(2):48-53; 1995.

Fungus gnats— *Bradysia* spp. (Diptera: Sciaridae)— thrive in high-moisture environments, particularly those common in greenhouses (Baker 1972, McHugh 1991). Adult fungus gnats are small, dark, mosquito-like insects that do not damage plants (McHugh 1991. Their presence is usually more of a nuisance than a production problem (Robb 1991) but the adults may disseminate fungal spores that can infect plants (Kalb and Millar 1986, Gardiner and others 1990).

The larvae are small and maggot-like, with white bodies and distinct black heads: they feed on organic matter in growing media, including decaying plant debris (Shrimpton 1991) and can damage seedling crops by feeding directly on roots (Wilkinson and Daugherty 1970, Dennis 1978, Hamlen and Wettstein 1978). Larvae are usually confined to the upper portions of plugs, where they can strip root hairs, tunnel through succulent stems, and feed on foliage, allowing infection by pathogenic fungi (King 1990). Seedling damage includes stunting and wilting, premature foliage loss, and chlorosis (King 1990), symptoms similar to those caused by root pathogenic fungi (James and others 1991).

Two species of dark-winged fungus gnat— *Bradysia impatiens* Johannsen and *B. coprophila* Lintner— are usually recognized in association with greenhouse crops (Gardiner and others 1990, McHugh 1991). The life cycle of *B. impatiens* is temperature dependent; the egg-to-adult cycle requires 49 days at 13 ºC (55 ºF) but only 20 days at 29 /C (85 /F) (Wilkinson and Daugherty 1970).

Little is known about the role of fungus gnats in the epidemiology of plant pathogenic fungi. Gardiner and others (1990), who evaluated interrelationships of gnats with *Pythium* root disease on different greenhouse crops and found high gnat populations during *Pythium* outbreaks, concluded that gnats were important in disease spread. Examination of gnat larvae indicated several *Pythium* structures were ingested: mycelium, oospores, and zoospore cysts. Larval digestive tracts were often packed with Pythium oospores, which readily germinated after passing through the larvae. In another study, Kalb and Millar (1986) demonstrated that adult *B. impatiens* are vectors of *Verticillium albo-atrum* Reinke & Berthier, an important root pathogen of alfalfa. Leath and Newton (1969) found that fungus gnat larvae feeding on alfalfa and red clover seedlings made the plants susceptible to infection by *Fusarium oxysporum* Schlechtend. emend. Snyd. & Hans. f. sp. *medicaginis.*

Because of the common association of dark-winged fungus gnats with fungi and the prevalence of fungi as potential causes of disease in greenhouse seedlings, we sampled dark-winged fungus gnats in greenhouses to identify the various species of fungi commonly carried by these insects.

Materials and Methods

Fungus gnats were trapped throughout the greenhouse production phase at two northern Idaho nurseries that grow conifer seedlings: USDA Forest Service Nursery in Coeur d'Alene and the University of Idaho Research Nursery in Moscow. Gnats were trapped either in open containers filled with water or on standard yellow sticky cards (figure 1). Traps were located near the surface of the medium. The traps were collected periodically and entire fungus gnat bodies, when possible, were transferred aseptically to agar

Figure 1—*Adult fungus gnat (*Bradysia *sp.) as it appears on a yellow sticky card.*

media in the laboratory. Standard potato dextrose agar and an agar medium selective for *Fusarium* spp. and closely related organisms (Komada 1975) were used. This latter medium is often used to isolate root pathogenic fungi from conifer seedlings. Selected fungi emerging from trapped fungus gnats were maintained in pure culture for identification purposes. Whenever possible, single-spore isolates were derived. Several taxonomic compilations were used for fungal identification (Dorenbosch 1970, Barnett and Hunter 1972, Domsch and others 1980, Nelson and others 1983).

Results and Discussion

Fungus gnats collected at the University of Idaho were identified as *B. coprophila.* Of all fungi emerging from adult fungus gnats, 25% were identified as *Botrytis cinerea* Pers. ex Nocca. & Balb. Another 25% were identified as *Aureobasidium pullulans* (de Bary) Arnaud. Six other species emerged at much lower levels; these were identified as *Phoma eupyrena* Sacc., P. *glomerata* (Corda) Wollenweb. & Hochapfel, *P. herbarum* Westend., *Fusarium proliferatum* (Matsushima) Nirenberg, *F. sambucinum* Fuckel, and *Oidiodendron griseum* Robak and are covered more thoroughly in James and others (1994). Of these species, *F. proliferatum is* probably the most important root pathogen of conifer seedlings (James and others 1991) and we identified only 4% of fungi emerging from fungus gnats as this pathogen. Unidentified, nonsporulating fungi accounted for about 8% of isolations. Often, more than one fungal species was isolated from a particular adult gnat.

Aureobasidium pullulans is a ubiquitous saprophytic fungus usually found on the surface layers of soil (McLennan and Ducker 1954, Kendrick 1963, Cooke 1970), and also on growing media and the aboveground portions of plants (Cooke 1961, Hermanides-Nijhof 1977). Some *A. pullulans* strains are especially well adapted to peat habitats (Christensen and Whittingham 1965, Latter and others 1967). This fungus may exhibit a dimorphic yeast-type phase (Domsch and others 1980); it is common within the seedling canopy and its spores may contaminate any insect encountering infected foliage (Domsch and others 1980).

Botrytis cinerea, gray mold, is a very important pathogen of greenhouse-grown conifer seedlings (James 1984, Mittal and others 1987, Landis and others 1989a), especially toward the end of the growing season when canopies are dense, temperatures cool, humidity high, and irrigation water on needles evaporates slowly (James 1984, Peterson and others 1988, Srago and McCain 1989, Sutherland and others 1989). The fungus requires senescent foliage (Peterson and others 1988, Dugan and Blake 1989) and long periods of wet needle surfaces or relative humidity near saturation (Carre and Coyier 1984, Peterson and Sutherland 1990, Zhang and Sutton 1994a) for infection. Under ideal conditions, *Botrytis* spores can germinate within 2 hours, infect host plants within 20 hours following spore germination, and produce more spores within 8 hours of host infection (Barnes 1993). This fungus causes disease primarily on above-ground portions of seedlings (James 1984) but can reside in roots, especially those just below the soil surface (James, unpublished data). Fungus gnat larvae may collect *Botrytis* spores when feeding on roots near the growing medium surface (McHugh 1991). Because *Botrytis* spores are commonly produced on shadecaused necrotic foliage near the base of seedlings (James 1984), it is also that likely adult gnats become contaminated as they emerge from the medium and/ or move through the lower portions of seedlings. The relatively high rate of adult fungus gnat contamination with *Botrytis* indicates that they may be important in translocating this pathogen within greenhouses.

Fungus Gnat and Botrytis Control

Fungus gnats and *B. cinerea* thrive in high-moisture environments and are ubiquitous in greenhouses.

Cultural control methods, including sanitation, water management, and growing regimes, can provide effective control of these pests.

Gnats require decaying organic matter and *Botrytis* requires dead or dying foliage to begin the disease cycle. Prompt removal of dead seedlings, weeds inside greenhouses as well as nearby weeds outside, cryptogams, and extraneous organic matter from benches, floors and walls reduces potential substrate for these organisms (Rutherford and others 1985, Sutherland and others 1989, Landis and others 1989a, Dumroese and others 1990, King 1990, Robb 1991).

Overwatering promotes population increases of both organisms. Excessively wet soils maintain high gnat populations (King 1990, Shrimpton 1991) and free surface moisture on needles is conducive for *Botrytis* infection (Carre and Coyier 1984, James 1984, Peterson and Sutherland 1990, Zhang and Sutton 1994a). Using a well-drained medium and allowing it to dry between irrigations impedes fungus gnat development (King 1990, Shrimpton 1991). This form of irrigation scheduling will also reduce cryptogam development (Landis and others 1989a). Growers may wish to check their irrigation efficiency and correct distribution problems that result in areas receiving excessive irrigation (Landis and others 1989b). Reducing irrigation frequency, irrigating early in the morning, and adding a surfactant to water reduces the time seedling foliage is wet, thus reducing conditions favorable to *Botrytis* infection (Sutherland and others 1989, Landis and others 1989a, Srago and McCain 1989, Dumroese and others 1990). Seedling foliage can also be brushed with plastic pipe or a wooden dowel to dislodge water droplets and encourage drying (figure 2). Besides reducing water necessary for spore germination and infection, reducing irrigation frequency would also help limit spore dispersal within greenhouses. Hausbeck and Pennypacker (1991) found that *any* cultural activity, especially irrigation of plant foliage, resulted in significant *Botrytis* spore dispersal. Other useful cultural controls include underbench ventilation and heating (Peterson and Sutherland 1990), growing seedlings at lower densities, spreading containers of susceptible species apart during periods of high seedling vulnerability (Landis and others 1989a), manipulating fertilizer regimes to maintain proper seedling size (Dumroese and others 1990), avoiding excessive nitrogen fertilization (Kingsbury 1989), and

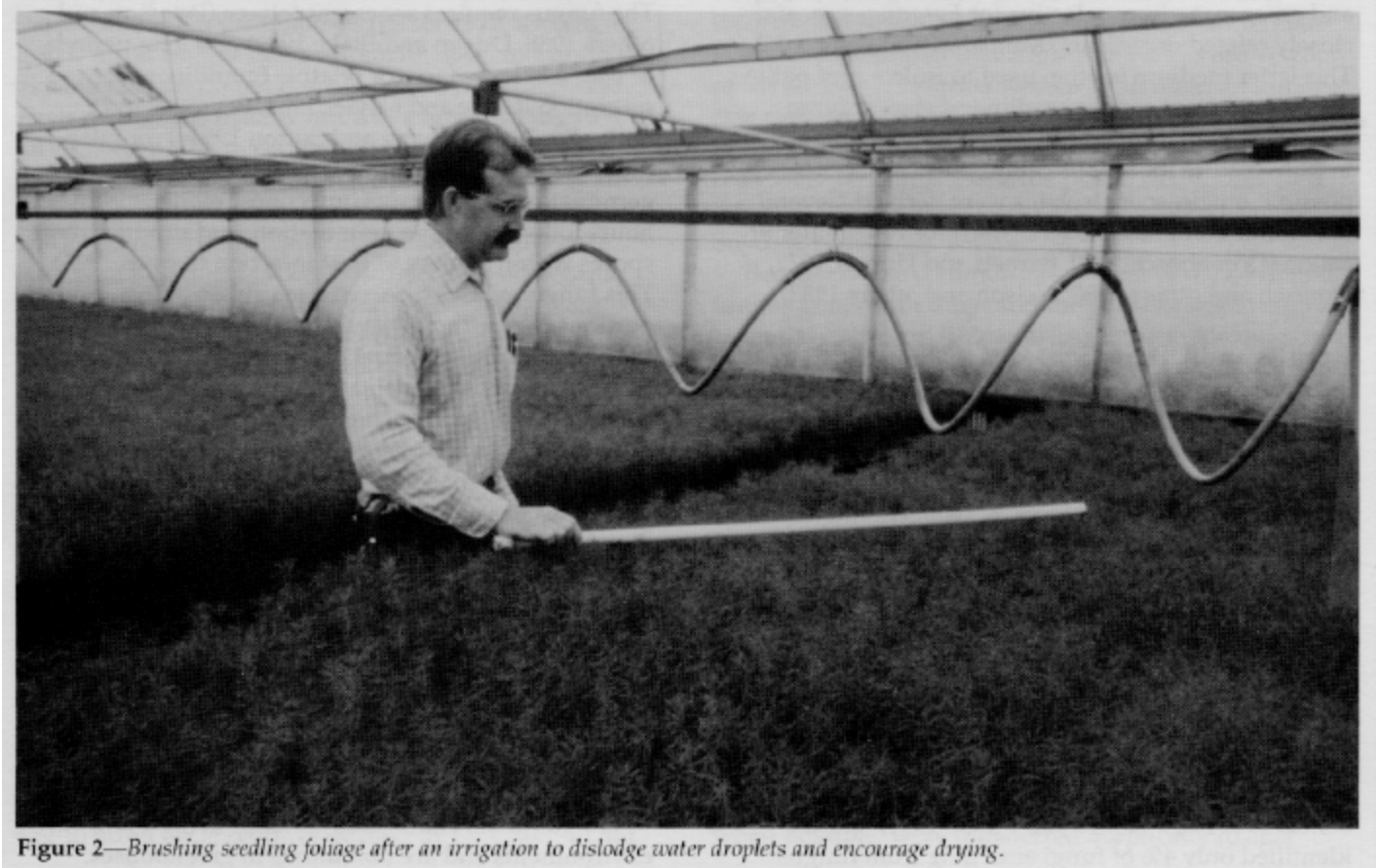

Figure 2—*Brushing seedling foliage after an irrigation to dislodge water droplets and encourage drying.*

removing roof and wall coverings from greenhouses to improve aeration and modify seedling growth (Sutherland and others 1989).

Populations of fungus gnats can be monitored on yellow sticky cards placed every 46 to 93 ml (500 to 1,000 ft^2) of greenhouse (Robb 1994) as adults are attracted to the color (Parrella 1987) (figure 3). White sticky traps placed in a "W" formation throughout the greenhouse are also effective for monitoring populations (Rutherford and others 1985). Traps work best if positioned low in seedling canopies or right at tray height. At high densities, sticky cards or ribbons can be used to control adult populations (Shrimpton 1986). At the University of Idaho, ten fungus gnats per block is the threshold at which biological or chemical control treatments are initiated (Dumroese and Wenny 1992).

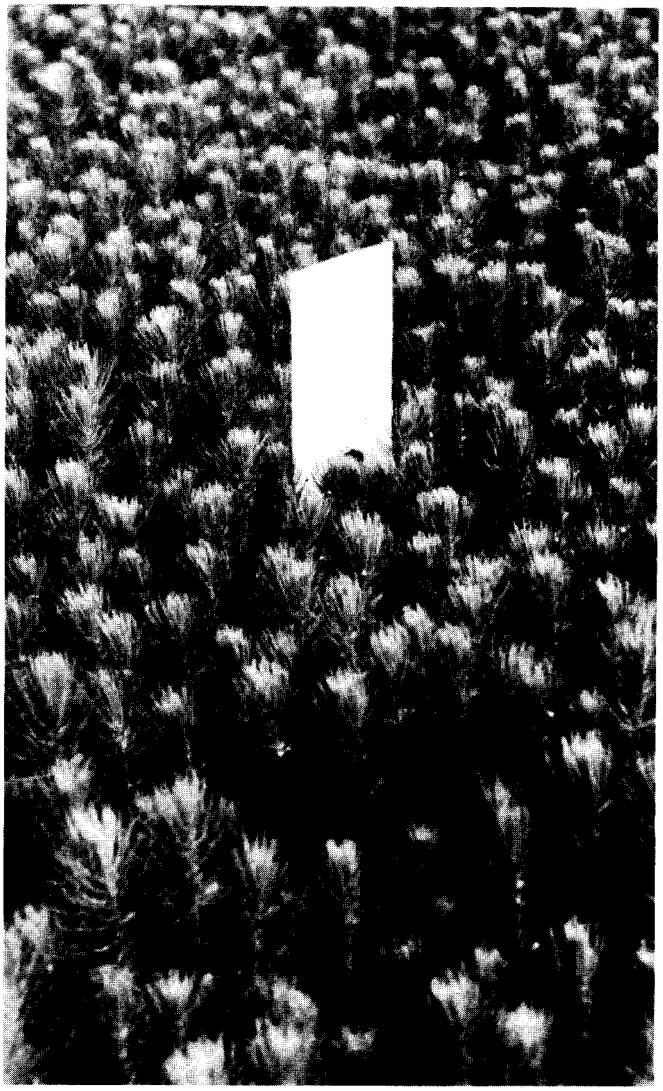

Figure 3—*Monitoring fungus gnats with a yellow sticky card.*

The larval stage is easier to control. Several biological control formulations are either currently available or being developed against fungus gnat larvae. Parasitic nematodes *(Steinernema* spp.*)* work well and are available under various trade names (e.g., Exhibit®) (King 1990, McHugh 1991, Lindquist 1993, Gill and MacLachlan 1994). These are applied as an aqueous drench onto the soil surface. *Bacillus thuringiensis* Serotype H-14 formulations (e.g., Gnatrol®) have also proven effective in greenhouses (King 1990, Lindquist 1993). In general, nematodes give longer control because they are active up to 6 weeks (perhaps 2 life cycles of the fungus gnats), whereas *B. thuringiensis* treatments only last a few days.

Chemical insecticides should usually be applied only in response to either very high insect populations or noticeable seedling damage (McHugh 1991). Routine pesticide applications are generally unnecessary and not recommended (Hussey and others 1969). Diazinon, bendiocarb, acephate, and oxamyl do control adult gnats effectively (King 1990) but must be applied repeatedly at weekly intervals or so to control successive generations of adults emerging from growing media.

Commercial biological control of *Botrytis* may soon be possible, either with antagonistic fungi (Sutton and Peng 1993, Zhang and Sutton 1994b) or saprophytic yeasts (Elad and others 1994). Landis and others (1989a) state that chemical control of *Botrytis* is impossible without a cultural control program in place. Chemical fungicides for *Botrytis* control have varying success. Commonly used fungicides include dicloran, chlorothalonil, and iprodione (James and Woo 1984). All fungicides must be applied before infection takes place, as there are considerable differences in efficacy between the chemicals and some chemicals provide better protection on some conifer species than others (Landis and others 1989a). Further, *Botrytis* may develop resistance to repeatedly used fungicides (Gillman and James 1980, Cooley 1981, James and Woo 1984, Glover and others 1987, Chiba and Northover 1988) so fungicide families should be used in rotation during the growing season.

Management Implications

Our study shows that *Botrytis cinerea is* the prevalent fungus carried through seedling crops by fungus gnats. Both fungus gnats and *Botrytis* grow best under the high-moisture environments of greenhouses and require either dead or dying foliage or decaying organic matter to complete their life cycles. Therefore, a combination of cultural controls including prompt

and thorough sanitation of seedling crops, avoidance of overwatering, and use of techniques that encourage rapid drying of seedling foliage can be an effective tool for reducing the incidence and severity of both pests. Although chemical pesticides may provide temporary relief to disease symptoms elicited by fungus gnats and Botrytis, long-term control can only be achieved through an integrated pest management plan.

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Oak Seedling Root and Shoot Growth on Restored Topsoil

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Five oak species were planted on land reclaimed after mining for coal in southern Illinois. The replaced soils were compacted and had been chisel-plowed. Tree numbers varied among the species and were chiefly affected by seedling establishment rather than later survival. Rooting depths of bur (Quercus macrocarpa *Michx.), pin* (Q. palustris *Muenchh.), chestnut* (Q. prinus *L.), and English* (Q. robur *L.) oaks greatly exceeded shoot height after 3 years. All species, and black oak* (Q. velutina *Lam.), had heights of 100 cm (40 in) or greater after 5 years. English oak was significantly tallest at nearly 200 cm (80 in). Animal damage varied among species.* Tree Planters' Notes *46(2):54-57; 1995.*

Reforestation projects are often carried out on soils unlike those on which the designated species occur naturally. Typical instances include urban settings, eroded abandoned fields, landfills, and reclaimed surface coal mines. The present study compared *5* oak species planted on fields with restored rooting medium after surface mining for coal. The uppermost soil layers of the pre-mining Hosmer silt loam had been selectively replaced. Compaction of these fine-textured soils from traffic ("tracpaction") by tractors, pan scrapers, and other heavy machinery was documented by a retired USDA Soil Conservation Service soil surveyor. These fields had been chisel-plowed or ripped.

Two series of plots were established. One had 4 oak species— English *(Quercus robur* L.), bur *(Q. macrocarpa* Michx.), pin (Q. *palustris* Muenchh.), and chestnut oak (Q. *prinus* L.) planted from seed in the autumn of *1988.* Both root and top growth were measured for 3 years, and top growth for *5* years. Other plots had pin oak from seed or black oak (Q. *velutina* Lam.) seedlings.

The objectives of this study were to determine the relative survival and shoot heights of 5 oak species and the rooting depths of 4 oak species on reclaimed land that had been graded, topsoiled, and chisel-plowed.

Materials and Methods

Rooting and growth study. Acorns of English, bur, pin, and chestnut oak were planted in November 1988 on a site in Saline County west of Harrisburg in southeastern Illinois that had been mined several years earlier. The field had been graded relatively level with replaced topsoil and ripped in 1987 to 60 cm *(*24 in) depth with a chisel plow and planted to oats followed by alfalfa.

We killed most of the alfalfa by spraying with glyphosate (Roundup®) herbicide at *2%* solution prior to tree planting, and followed up with wick application of glyphosate to alfalfa sprouts. Simazine (Princep 4G®) at 44 kg/ha (50 lb/acre) was spread on the plots in spring 1990 and at *62* kg/ha (70 lb/acre) in spring 1991. The aisles between plots, planted to red fescue *(Festuca rubra* L.) , and some weedy plot areas sparsely occupied by tree seedlings, were mowed in the first *2* years.

The experimental design was a 4 x 4 Latin square with 16 plots. A species was randomly located once in each column and once in each row of the Latin square. A plot had 12 rows with 12 seed spots per row on 1-m spacing. There were 576 seed spots per species, 144 per plot.

The English, bur, and chestnut oaks are in the white oak group that fall-germinate when ripe in the autumn. We planted 1 acorn if it had germinated, otherwise *2* acorns, of these species and pin oak in each seed spot in the fall. The English oak acorns were collected from trees planted about 1970 in Carbondale. Most of the chestnut oak acorns, which were obtained from southern Maryland, had germinated and their roots, which were between 5 and 15 cm *(*2 to 6 in) long, were trimmed to *5* cm (2 in) before planting. Acorns with roots > 15 cm (6 in) long were not planted. The bur and pin oak acorns were collected from sites in southern Illinois. We took care to keep the acorns from drying

out and becoming non-viable before planting (Bonner 1993).

Number of seed spots with a tree seedling were counted in spring 1989 (year 1) and each autumn for years 1 to 5. If a second seedling was present, it was clipped off. Percentage survival was calculated as the number of seed spots with a tree present each autumn divided by the original number of trees established in spring of year 1. Notes were taken periodically on mammal damage. Insect and disease problems were not evident. Root depths were determined for 1 or more trees judged to be typical of each species per plot (4 or more trees of each species per year) in the first 2 years by hand digging, and the third year by using a backhoe followed by hand digging.

Tree heights were taken each autumn for 5 years. Statistically significant differences in height among the species were determined using an ABSTAT® program for analysis of variance and between species were determined using the Scheffe test at a level of " = 0.05.

Growth study. One plot was planted in April 1989 with additional pin oak acorns that had been stratified at 5 ºC over winter. Roots were starting to grow when planted, 2 per seed spot, and the seedlings emerged at about the same time as the fall-planted acorns of the rooting study. The soil of this plot area had been ripped with a 2-spike ripper to 80 cm (32 in) depth in 1988 and planted to oats.

Two plots were planted to black oak seedlings in April 1989. One was next to the pin oak plot on the ripped area, and the other near the oak rooting study on the chisel-plowed area. These 3 growth-study plots were treated with herbicide the same as the other plots with Princep 4G in spring 1990 and 1991 and mowed as feasible and needed. Trees in the growth study were counted and measured each year.

Results

Rooting and growth study. Although the 4 oak species differed in number of trees established the first spring, subsequent percentage survival was relatively similar (table 1). All species had a small increase in number of trees from 1989 to 1993.

Rooting depths of bur, pin, and chestnut oak in the first 3 years were more than double their heights (figure 1). The differences were less great for English oak. There were major differences in the nature of the root systems. The bur oak roots were relatively massive and more roots penetrated to lower depths. Chestnut oak root penetration was least deep and thorough. Only a slender root penetrated to the depths

Table 1-*Number of trees established in spring 1989 and 5-year percent survival and height of 5 oak species on replaced topsoil*

	No. of trees in spring 1989	Survival 1993 (%)	Height 1993 cm	Height 1993 in
Rooting and growth study'				
English oak	263	107	192†	75.6†
Bur oak	157	101	113	44.5
Pin oak	71	104	104	40.9
Chestnut oak	54	106	106	41.7
Growth study				
Pin oak‡	100	95	117	46.1
Black oak§	245	95	108	42.5

Each species had 576 total seed spots planted in fall 1988.

† Height was significantly greater than other species.

‡ One plot with 144 seed spots planted in spring 1989.

§ Two plots planted with a total of 288 seedlings in spring 1989.

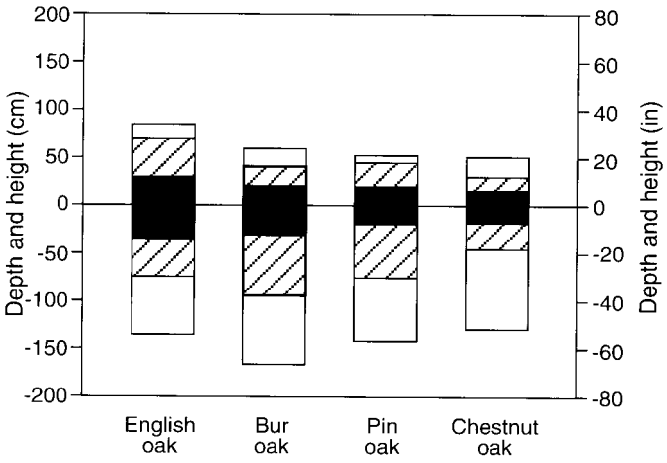

Figure 1— *Mean rooting depth and shoot height of 4 oak species at ages 1, 2, and 3 years on a chisel-plowed compacted rooting medium. English oak third–year height was statistically significantly greater.*

listed. The ratio of top-to-root length was highest for the English oak.

The 5-year shoot heights of bur, pin, and chestnut oak were roughly equivalent and significantly less than that of English oak (table 1). Tender new terminal shoots of the tallest trees, chiefly English oak and a few bur oak, were commonly broken off each spring by birds perching on them.

All species had some type of mammal damage (table 2). Bur oak trees were especially damaged from girdling by voles and nipping by rabbits. Pin oak trees were least damaged, discounting an initial substantial

Table 2-*Percent of trees in the rooting and growth study with animal damage in year 5*

	Percent seedlings with animal damage				
	Girdled (vole)	Nipped (rabbit)	Browsed (deer)	Rubbed (Buck deer)	All types
English oak	0.4	0.4	0.0	1.4	2.2
Bur oak	12.6	3.8	0.6	0.0	17.0
Pin oak	0.0	1.4	0.0	0.0	1.4*
Chestnut oak	7.0	0.0	3.5	0.0	10.5

* Many of the small pin oak acorns were pilfered over winter.

loss of acorns over winter. Damage overall was probably more severe than observed.

Growth study. The pin oak spring-planted acorns had higher establishment and somewhat lower percent survival after 5 years than did the fall-planted root-study trees (table 1). Height tended to be somewhat greater. The black oak spring-planted seedlings established well and had similar survival to the pin oak. Five-year height was similar to the other oaks except English oak. Survival and height of black oak on the chisel-plowed or ripped plots were similar and were combined in table 1.

Discussion

Establishment was a critical stage for all 5 oak species. The number of trees surviving at one year adequately represented species numbers at 5 years. Mining companies, highway planting contractors, and others could well replant as early as possible in the first year to minimize the period for bond release or to avoid penalty payments if initial establishment of oaks were deficient. The slight increase in the number of trees from year 1 to 5 could have resulted from delayed top growth, recovery after early animal destruction of their tops, and increased visibility to the researcher as the trees became larger.

There was no evidence that this mined area was visited by squirrels that would take the relatively large acorns of English, bur, or chestnut oak. Both black and pin oak have relatively small acorns that may be dug up by field mice. A plastic pot label had been placed at each seed spot, and for pin oak many of the labels later marked holes where acorns had been pilfered. In a recent unpublished study, we found that squirting Surf® laundry detergent on the soil surface at each planting spot resulted in very few acorns being dug up over winter. Spring planting of pin oak acorns and use of black oak seedlings avoided winter losses in our growth study. Least-good establishment of chestnut oak apparently resulted from too long a delay in planting the acorns.

Although deer were seen occasionally, damage to the developing trees compared to other plantings may have been lessened because the plots were within sight of a house and dogs roamed at the edge of town. Only the bushy English white oak was big enough to be used for typical buck rub, and its many branches likely somewhat protected the trunks. In the past 25 years, no evidence of spreading by this introduced oak has been noted in the Carbondale area.

Acorns were planted to avoid possible effects of poorly planted seedlings on root systems. The main characteristic of the soil that could affect root development seemed to be soil strength, which varied enormously with moisture content. The soils when dry were so hard that digging with a shovel was not possible and using a pick would damage the roots. Excavations were postponed until the soil was moister and less hard. Roots in the lower soil depths were commonly strongly flattened along a crack in the soil. By year 2 root depths of bur, pin and English oak were below the 60-cm (24-in) depth of chisel plowing.

Root excavations were not attempted after the third year. The labor of digging out deeper roots, even using a backhoe, became excessive. Also, by that time all species had reached the mandated depth of the rooting medium under current mining regulations and could exploit the lower, mineral-rich mixed overburden materials. Roots that penetrate a topsoil cap often develop well in coarser-textured underlying materials (Ashby and others 1984).

Fine-textured replaced minesoils that have been graded and compacted are anaerobic from the perched water tables that lie above compacted layers during winter/early spring and rainy periods in the growing season. Mid-summer drought periods are characteristic of the southern Illinois climate. That English oak has grown well in urban forestry in southern Illinois on a fragipan soil, Hosmer silt loam, suggests a similar adaptation to that of pin oak to alternately saturated and droughty soils.

The native oaks differ in their ecological habitat distributions in nature (Burns and Honkala 1990). In southern Illinois, bur and pin oak are most commonly found on poorly drained bottomlands, and black and chestnut oak on well-drained ridges. Only black oak was a component of the tree cover on a nearby pioneer cemetery.

Pin oak, the only 1 of our 5 species reported in another study, was the least deeply rooted of 6 species after 8 years growth on a graded and compacted minesoil with replaced topsoil (Ashby and McCarthy

1990). The deepest rooting species was baldcypress *(Taxodium distichum* (L.) Rich). A lack of close correspondence between shoot height and rooting depth in that study, and in the present one, suggests that factors such as drought resistance are also important in tree performance on compacted soils.

There were statistically significant differences in tree height between rows, and columns, of the Latin square using the Scheffe test. This amount of variation in height growth in a relatively small area (54 x 54 m or 177 x 177 ft) needs to be considered in interpreting results of studies with reclamation tree plots. The plot area seemed uniform when the acorns were planted.

Conclusions

Tree numbers of each species after 5 years were chiefly determined by rate of first-year establishment and very little by the subsequent mortality. Various kinds of animal damage affected growth of the several oak species each year.

Roots of the 4 selected oak species penetrated to the depth of replaced fine-textured soil materials within 3 years after planting. Bur oak had the deepest and most massive roots. English oak was tallest and had the highest top-toroot ratio.

Chestnut oak does not seem to be as well-suited for planting on fine-textured, compacted and chiselplowed soils in southern Illinois as bur, pin, and black oak. Fallplanted pin oak acorns need to be protected from pilfering by animals. English oak seemed most suited for settings where non-native species are valued.

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Improved Vegetative Propagation of Scouler Willow

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Demand has exceeded supply for conservation plantings of Scouler willow (Salix scouleriana *Barratt ex Hook.). To test possible ways to improve propagation, we treated 8- to 10-cm-long (3.2- to 4.8-in-long) hardwood cuttings with 0.0, 0.1, 0.3, 0.8, and 1.6% indole-3-butyric acid (IBA), and 5- and 10-cm-long (2- to 4-in-long) softwood cuttings, with 0.0 and 0.3% IBA. Best rooting (73% and 87%) occurred after treatment with 0.3% IBA in the hardwood and 10-cm long softwood cuttings, respectively. Microshoots were tested with the antibiotic cefotaxime and calcium gluconate to control bacterial contamination and shoot-tip necrosis. Microshoots, with or without naphthaleneacetic acid (NAA), rooted up to 92% both* in *and* ex vitro *without NAA. Similar micropropagation options may improve production of other difficult to propagate willows.* Tree Planters' Notes 46(2):58-63; 1995.

Many revegetation projects plant native willows to rehabilitate damaged habitat. Scouler willow *(Salix scouleriana* Barratt ex Hook.), an upland (non-riparian) willow of western North America, is useful for stabilizing steep erodible banks on drier sites above river courses. Scouler willow, however, does not root as readily as other willow species used for riparian revegetation (Platt and others 1987).

Willow cuttings develop adventitious roots from either the entire buried stem or from a restricted region at the base of the cutting, but species that produce basal roots are generally more difficult to propagate (Chmelar 1974). Only 4.5% of Scouler willow hardwood cuttings developed basal roots (Densmore and Zasada 1978). However, 78% of hardwood cuttings that were wounded and then treated with a powder containing 0.8% indole-3-butyric acid (IBA) achieved rooting success (Holloway and Zasada 1979). Alternative powder formulations, however, were not evaluated. Softwood (greenwood) cuttings rooted at a rate of 64% after similar treatment, but only about 50% of the rooted cuttings survived transplanting and only 38% of the surviving transplants survived 1 year.

Fog humidification and micropropagation methods have improved the propagation of many difficult-to-propagate species (Hartmann and others 1990). Survival of micropropagated *Salix schwerinii* (E. Wolf) was higher than that of conventional rooted cuttings (Gupta and others 1991).

Because demand has exceeded supply for conservation plantings of Scouler willow and propagation of softwood cuttings has been limited using conventional methods, we used fog humidification and micropropagation technology to develop improved vegetative propagation of the species. We evaluated rooting success and greenhouse survival of hardwood and softwood cuttings propagated under fog humidification and microshoots propagated *in vitro.* We established an optimal level of IBA powder treatment for hardwood cuttings, improved the rooting rate of softwood cuttings, and developed efficient *in vitro* multiplication and rooting procedures.

Materials and Methods

We conducted propagation studies with three types of cutting material:

1. Hardwood— dormant stems collected from the wild
2. Softwood— new shoots of the rooted hardwood cuttings
3. Microshoots— new shoot tips of rooted hardwood and softwood

Hardwood and softwood cuttings were macropropagated in a greenhouse, and microshoots were micropropagated in a laboratory.

Macropropagation techniques. For hardwood propagation material, 1-m-long (3.3- ft-long) dormant whips were harvested in April from several hundred genotypes from the Krassel Ranger District of the Payette National Forest in central Idaho and from Clearwater and Latah Counties of northern Idaho. These whips were stored for 3 weeks at 2ºC before propagation. Hardwood cuttings— 8- to-12-cm-long (3.2- to 4.8- in-long) stem segments— were then prepared according to the methods described by McCluskey and others (1983). For softwood (green-

wood) propagation materials, cuttings of partially lignified shoot tips were collected in mid-summer from container-grown rooted hardwood cuttings propagated the previous year.

Both softwood and hardwood cuttings were sized with a cut made directly below a node at a 45º angle, after which the stems were soaked for 30 sec in a fungicidal dip of 1 g/1 benomyl before setting in a 1:1:1 (v/v/v) mixture of peat, perlite, and vermiculite. The propagation trays were placed on a rooting bench under 88 to 92% relative humidity, natural photoperiod, and 70%o shade. Shoot tips and lower leaves of softwood cuttings were removed, leaving the uppermost leaves intact. Cuttings were not fertilized. Rooted cuttings were transplanted to polystyrene block (315A) containers (with one-hundred sixteen 75-ml-capacity cells) and received twice-weekly nutrient applications of 20:20:20 N/P/K at rates increasing from 50 to 200 ppm nitrogen over several weeks.

Determining optimal IBA levels for hardwood cuttings. To assess IBA's effect on rooting success, on May 1, 1992, cuttings were assigned to four replicates, 40 cuttings per replicate treatment, of 0.0, 0.1, 0.3, 0.8, and 1.6% IBA, arranged in a randomized complete block design. Two months after initiation, cuttings with roots longer than 2 mm (0.08 in) were counted. Both live and dead rooted cuttings were tallied after 6 months. Shoot extension and the number of plagiotropic leaders were recorded after terminal budset. A total of 45 plagiotropic rooted cuttings were transplanted to a polystyrene block (615A) container (with forty-five 340-mlcapacity cells) and retained for observation during 1993.

Evaluating short cutting length in softwood cuttings. The optimal IBA level for hardwood cuttings was chosen to test the rooting response of softwood cuttings. Because shoot availability for softwood cuttings was limited, the effect of short cutting length on rooting was evaluated. On July 29, 1992, softwood cuttings were assigned to four replicates, 50 cuttings per replicate treatment, of short stems (5 cm, or 2 in) and long stems (10 cm, or 4 in) with and without a basal powder dip of 0.3%o IBA, arranged in a 2 x 2 factorial randomized complete block design.

Rooting success was tallied monthly for 3 months. The number of roots longer than 2 mm per rooted cutting and length of the longest root per rooted cutting were recorded after 1 month. A random sample of 35 cuttings were measured for leader lengths and overall survival levels after 3 months' growth.

Micropropagation techniques. *Initiation and incubation.* Microshoots were unlignified shoot tips collected from new growth on potted plants in the greenhouse. Leaves were removed and stem tips were surface sterilized in a 20%o solution of laundry bleach for 20 min and rinsed three times in sterile, distilled, deionized water. Explants were cut into 2-node stem segments and placed on Murashige and Skoog medium (MSM) (Murashige and Skoog 1962). Within a few weeks, new leaves were turning yellow, white, and brown and then falling off. Explants were moved to woody plant medium (WPM) (Lloyd and McCown 1980) containing 0.1 mg/1 of the cytokinin benzyladenine (BA). New green leaves appeared and axillary buds broke, forming multiple shoots per explant. These and all subsequent cultures were maintained under cool-white fluorescent lights (40 W), which produced approximately 20 µmol/m^2/sec PAR on the leaf surfaces. Diurnal temperatures ranged from 22 to 27 °C.

To increase the number of microshoots available for experiments, axillary shoots were excised monthly from the cultures and transferred to fresh WPM + 0.1 mg/1 BA until sufficient numbers of uniform healthy microshoot tips were produced. Microshoots formed an average of 4.9 ± 0.4 new shoots each month.

Bacterial contamination. Many microshoots had an internal bacterial infection that spread and multiplied on the agar medium, sometimes overwhelming the microshoot. To control these bacteria, microshoots were given the antibiotic cefotaxime in WPM at 0, 200, and 300 mg/1 (100 replicates per treatment), arranged in a completely randomized design.

Shoot necrosis. Many shoot tips in the maintenance cultures turned black, possibly because of a calcium deficiency (Sha and others 1985). A total of 800 microshoots were assigned to treatment groups that were placed in WPM with or without calcium gluconate under high light (50 µmol/ m^2/sec) or low light (18 µmol/m^2/sec), arranged in a 2 x 2 factorial completely randomized design. The number of microshoots with black shoot tips was recorded after 1 month.

In vitro *rooting.* Healthy shoot tips were assigned to two treatments (90 replicates per treatment) of WPM + 0.1 mg/1 of the rooting hormone naphthaleneacetic acid (NAA) or WPM + 0 hormone (controls) in a completely randomized design. The microshoots were cut to 1.5 cm (0.6 in) and their bases were inserted 0.5 cm into the gel media. Rooting success was tallied weekly for 4 weeks, and the number of roots longer than 2 mm (0.08 in) and length of the longest root per rooted cutting were recorded after 1 month.

Ex vitro *rooting.* Shoot tips were inserted 0.5 cm into a 2:1:1 (v/v/v) sterile mixture of perlite, peat, and vermiculite in a germination tray. Half of the

microshoots (26) were dipped in Rootone® (0.2% NAA + 4.04% thiram) for 5 sec and the other half were dipped in water. The microshoots were placed in a fog humidification chamber and covered with a 20% shade cloth for several days. Rooting success was recorded weekly for 3 weeks.

Data analysis. Summaries of continuous and count data were expressed as the sample mean ± standard error. Counts of rooting success, contamination, and shoot tip necrosis underwent categorical loglinear maximum likelihood analysis of variance (PROC CATMOD, SAS Institute, Cary, NC, USA). Treatment comparisons were made by single degree of freedom contrasts at " =0 .05.

Results

Macropropagation. *Hardzvood cuttings.* Hardwood cuttings treated with 0.3% IBA had the highest average rooting rate (table 1), 17% more than untreated cuttings (P = 0.0006) and 24%, higher than cuttings in the 1.6% IBA treatment (P = 0.0002). By 6 months, however, the number of rooted cuttings declined by over 10%, with mortality associated with dieback and stem canker symptoms typical of *Cytospora* spp. (Westcott 1971).

After 3 months' growth, new shoots had extended an average of 18.3 ± 1.0 cm (7.2 ± 0.4 in). Initially, 73% of the rooted cuttings grew plagiotropically. In 1993, the transplanted plagiotropic plants developed an orthotropic form typical of Scouler willow. Furthermore, shoots released from below the plug surface often became detached from the cutting by natural growth and produced a less vigorous root system (figure 1), possibly because of the loss of their carbohydrate source.

Softwood cuttings. Adventitious roots appeared within 10 days and 85% of the rooting occurred within 4 weeks of setting the cuttings (figure 2). No further rooting was observed after 8 weeks. Of the 541 cuttings

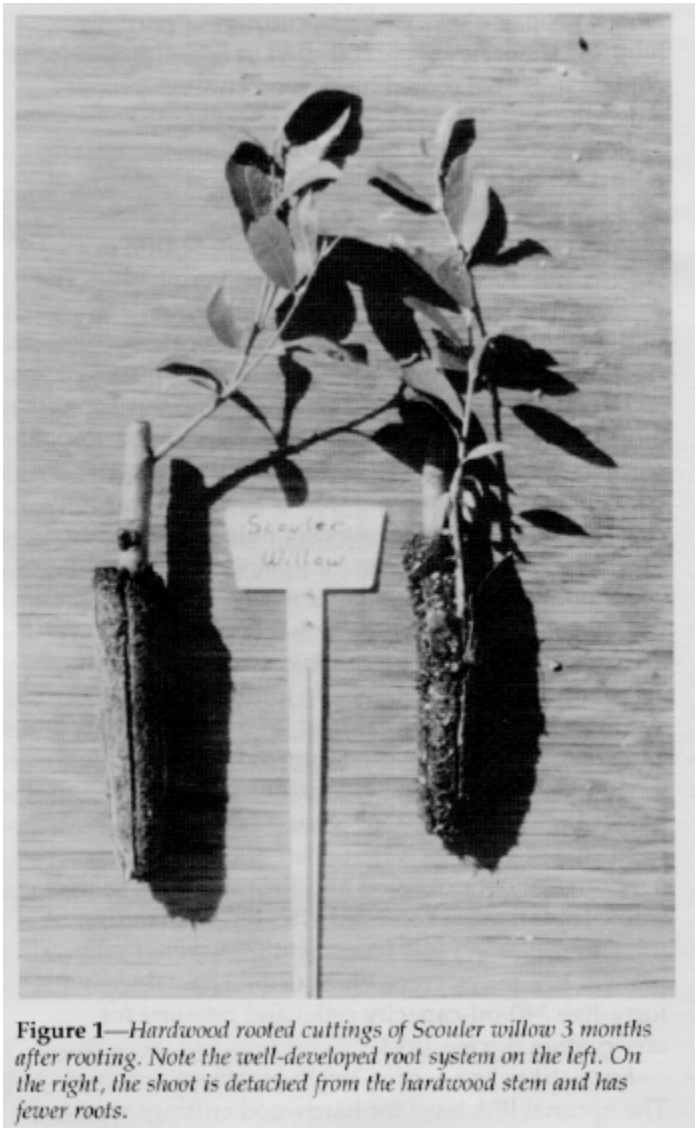

Figure 1—*Hardwood rooted cuttings of Scouler willow 3 months after rooting. Note the well-developed root system on the left. On the right, the shoot is detached from the hardwood stem and has fewer roots.*

Table 1-*Influencc of IBA on the rooting of hardwood cuttings 8 weeks after treatment with alternative powder formulation (n = 160)*

	0.0% IBA	0.15% IBA	0.3% IBA	0.8% IBA	1.6% IBA
Rooting success (%)	56 a	64 abc	73 c	63 ab	49 a
Survival (%)	48 a	55 ab	62 b	41 a	43 a

Within rows, treatment means with the same letter are similar as determined by contrasts of maximum likelihood estimates, "= 0.05. Maximum likelihood ANOVA of treatment effect yielded X^2= 28.56 (P= 0.0001).

rooted (67.6%), 9.2% died on the rooting bench with stem canker symptoms.

Both longer cutting length and auxin treatment resulted in enhanced rooting success (P < 0.0001). An average of 41% more of the 10-cm-long (4-in-long) cuttings treated with 0.3% IBA rooted than the 5-cm-long (2-in-long) cuttings lacking IBA treatment (table 2). The longer softwood cuttings produced slightly more roots per rooted cutting but the maximum root length remained constant. Cuttings developed overall averages of 3.4 roots per rooted cutting and maximum root length of 4.8 cm (1.9 in). After 3 months' growth, new shoots extended an average of 20.3 ± 1.3 cm (8.1 ± 0.5 in) with generally well-developed root systems.

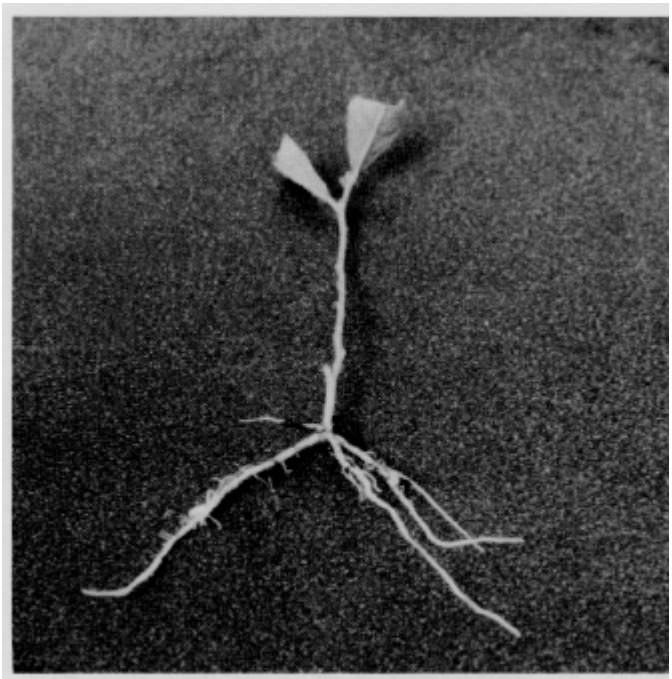

Figure 2—*A softwood rooted cutting of Scouler willow 3 weeks after setting. The shoot tip was removed and the upper leaves cropped to reduce transpiration.*

Table 2-*Effects of cutting length and .3% IBA treatment on the average proportion of softwood cuttings rooted, roots produced per rooted cutting, and maximum root length*

Length (cm)	% IBA	% Rooting (n = 200)	Ave no. roots per cutting	Ave length of longest root (cm)
5	0.0	46 a	2.8 ± 0.3	6.7 ± 1.4
5	0.3	68 b	2.9 ± 0.5	4.7 ± 0.9
10	0.0	65b	4.3±0.7	5.5±1.0
10	0.3	87c	4.5±0.5	5.5±0.9

Treatment means for percent rooting with the same letter are similar as determined by contrasts of maximum likelihood estimates, " = 0.05. The additive model (with factoral interaction p = 0.3390) produced a likelihood ratio $X^2 = 12.81$ ($P = 0.2343$).

Micropropagation. *Bacterial contamination.* After 1 month from the beginning of the experiment, we found that, as cefotaxime concentrations increased from 0 to 200 to 300 mg/1, bacterial contamination decreased significantly from 100 to 46 to 32%, respectively ($P < 0.05$). Just as important, we found that growth and development of microshoots was not inhibited by the antibiotic. Control microshoots produced an average of 6.8 new shoots a month compared to 8.9 and 8.0 new shoots produced by microshoots treated with 200 and 300 mg/1 cefotaxime, respectively.

Shoot necrosis. After 1 month, the combination of high light intensity (50 µmol/m^2/ sec) and addition of calcium gluconate to the culture medium completely inhibited the formation of black tips. The next best treatment, high light without calcium, produced significantly more dead tips than the high light with calcium ($P = 0.02$) (3% vs 0%, respectively). The low light (18 µmol/m^2/sec with calcium and low light without calcium treatments increased the number of dead tips (14% and 58%, respectively) as compared to the high light treatments, although the low light with calcium showed significantly less necrosis than without the calcium ($P < 0.0001$).

In vitro *rooting.* Microshoots rooted vigorously during the first 2 weeks (figure 3), the shortest time of any rooting method in our study, with only a few microshoots rooting in the third and fourth weeks. Control microshoots (0 NAA) rooted at 87%, which was not significantly different from the 92% rooting of NAA-treated microshoots, but the addition of NAA to the medium significantly increased the number of roots formed on each plantlet as compared with the control ($P < 0.01$) (table 3). Roots formed on control microshoots were significantly longer, though, than those roots initiated on NAA-treated cultures ($P < 0.01$) (table 3). All transplanted plantlets survived.

Ex vitro *rooting.* After 3 weeks, all rooting had taken place. Control microshoots rooted at 92.3% as compared to microshoots treated with Rootone® (57.7%). Thirty-eight percent of the microshoots treated with

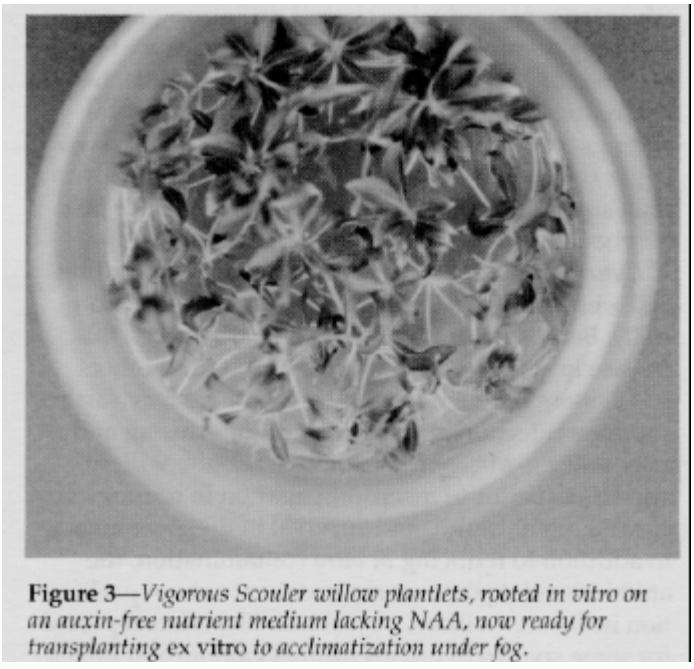

Figure 3—*Vigorous Scouler willow plantlets, rooted in vitro on an auxin-free nutrient medium lacking NAA, now ready for transplanting* ex vitro *to acclimatization under fog.*

Table 3-*The effect* of *NAA on rooting of Scouler willow microshoots after 3 weeks of exposure to 0.1 mg/l NAA*

Treatment (mg/I NAA)	% Rooting (n = 90)	Ave no. roots per plantlet	Ave length of longest root (cm)
0.0	87 a	2.36 a	2.53 a
0.1	92a	3.41 b	2.17b

For percent rooting, treatment means with the same letter are similar as determined by contrast of maximum likelihood estimates. "= 0.05. For average no. of roots or length of longest root, means with the same letter are similar as determined by the Cochran and Cox approximation

Rootone rotted whereas only 8%, of the control microshoots blackened.

Discussion

Best rooting successes suggest that Scouler willow softwood cuttings can root at least as well or better (87%) than hardwood cuttings (73%). This contrasts with a reversed trend previously reported by Holloway and Zasada (1979, who found that softwood cuttings (64%) rooted less than hardwood cuttings (78%). The higher softwood rooting rate attained in our study may have been enhanced by using fog humidification rather than conventional misting. Our optimal hardwood treatment of 0.3% IBA produced a similar result to the 0.8% IBA treatment of Holloway and Zasada (1979), but the rooting decline with 0.8 and 1.6% IBA suggests that hardwood cuttings require only moderate 1BA concentrations to enhance rooting. Cuttings rooted from softwood have the additional advantages of producing normal orthotropic shoots and fully occupying the container cell. Because the presence of a large stem in a plug, whether attached or not, reduces potential root volume, both softwood cuttings and micropropagated plantlets can produce a larger root volume than hardwood shoots for a given plug size, which in turn could possibly enhance field survival.

Cytospora infections are exacerbated by wounding and wet conditions (Filip and others 1992, Westcott 1971). Because benomyl treatment has reduced this disease in some hardwood trees (Spotts and others 1990), more frequent fungicidal treatment may further suppress infection in softwood cuttings during and after rooting. Micropropagation of Scouler willow appears superior to macropropagation in rooting success, plant health, and survival in the greenhouse. In addition to reducing *in vitro* contamination, the antibiotic cefotaxime seems to enhance shoot proliferation in Scouler willow, a cytokinin-like effect reported for some species in tissue culture (Valobra and James 1990). Increased light reduces shoot-tip necrosis, and calcium added to the culture medium provides further benefit, particularly in low light conditions. Calcium supplements have reduced shoot-tip necrosis in other species (De Block 1990, Sha and others 1985). In contrast with the apparent exogenous auxin requirement for optimal rooting of macrocuttings, auxins seem unnecessary to promote rooting of microshoots. Auxin treatment also may inhibit *ex vitro* root formation by increasing microshoot mortality.

Because results achieved were similar for the many genotypes collected from widely separated areas of central and northern Idaho, the propagation protocols are likely to be broadly useful for propagating Scouler willow.

Conclusions

This propagation study of Scouler showed that the rooting rate of softwood cuttings could be improved and developed an efficient method to micropropagate the species. These promising alternative options to hardwood propagation could increase the flexibility of producing stock for conservation plantings. With plentiful, disease-free cutting material available, propagating softwood cuttings could provide more stock plants with a larger root mass than rooted hardwood cuttings. The option to micropropagate Scouler willow can produce microshoots that root faster and survive at higher rates in the greenhouse than either softwood or hardwood cuttings, minimizes stem disease, bulks up propagation material rapidly when cutting material is in short supply, and allows year-round production. The protocols developed here should improve nursery production of Scouler willow. A similar approach of applying softwood and micropropagation options to other upland, nonriparian willows may improve production of other species now considered difficult to propagate.

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Estimating Pollen Yield From Western White Pine: Preliminary Studies

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Two preliminary studies were conducted to develop a method for quantifying the number of pollen cones and pollen yield by western white pine (Pinus monticola *D. Don). In study 1, pollen-bearing shoots from 10 trees in a single stand were sampled to obtain shoot attributes and determine pollen cones per shoot. "Pollen zone" (PZ), the length of shoot occupied by pollen cones, was the most useful feature to predict the number of pollen cones per shoot (CONES). The regression of pollen cones on PZ differed among trees, indicating the need for separate data per clone for very accurate estimates. In study 2, pollen volume per cone collected from two more trees averaged 0.22 cm^3; an average shoot bore 22.4 cones and produced 4.9 cm^3 of pollen. Procedures for estimating the pollen crop and for collecting a specified volume are offered.* Tree Planters' Notes 46(2):64-69; 1995.

Tree-improvement programs for western white pine *(Pinus monticola* D. Don) exist throughout its range. Seed orchards have been established, or are planned, in all programs to produce regular crops of high-quality seeds for reforestation. Like other pines, western white pine is slower to produce pollen cones than seed cones, prompting most orchard managers to collect and apply pollen to promote greater cone retention and increase seed production. Such supplemental pollination allows managers to broaden the seed-crop gene pool and can offset imbalance in reproductive output among orchard genotypes (Schoen and others 1986).

Despite the widespread focus on pines in genetic and tree-improvement programs, little information was found concerning the number of pollen cones per shoot. Himalayan pine (*P. griffithii* McClelland), a "soft" pine like western white pine, has 15 to 35 pollen cones per shoot (Konar and Ramchandani 1958), whereas Chir pine (*P. roxburghii* Sarg.), a "hard" pine, has 120 to 140 (Konar 1960).

Yield of pollen per cone in pines has been reported seldom. Ho and Owens (1973) reported an average of 15 pollen cones per shoot, yielding an average of 8.9 million grains, on three trees of lodgepole pine *(P. contorta* Loud.). Jett and others (1993) estimated pollen yield by loblolly pine (*P. taeda* L.) as 6.2% of the volume of cones, and of 4.5% for Scots pine *(P. sylvestris* L.). The only comparison of pollen yield and cone mass found was that made by Sarvas (1962), who found that the weight of Norway spruce *(Picea abies* (L.) Karst.) pollen produced was approximately double the weight of exhausted pollen cones. Caron and Powell (1989) found a positive correlation between the number of trapped pollen grains and the number of pollen cones per tree.

Hoff and Coffen (1982) recommend collecting data yearly on the seed-cone and pollen crops in western white pine seed orchards in order to quantify the balance in reproductive effort. They represented the pollen crop in classes of catkin (that is, pollen-cone) clusters, rather than as numbers of cones or volume of pollen.

Because no data were found expressing pollen yield per shoot in western white pine, two small studies were conducted. Study 1 was designed to test for the relationship between shoot and pollen-zone lengths and number of pollen cones per shoot, whereas study 2 focused on the relationship between the number of pollen cones per shoot and the amount of collectable pollen per pollen cone ("catkin" or microstrobilus). The results are intended to assist orchard managers in estimating pollen crops more accurately and tree breeders and orchardists in collecting desired amounts of pollen.

Materials and Methods

Study 1. *Estimating pollen buds per shoot.* Ten open-grown trees in a natural stand of western white pine in British Columbia described in El-Kassaby and others (1987) were selected during a "good flowering year." Trees ranged in age from 34 to 38 years, from 6 to 10 m in height and from 12 to 25 cm in dbh. Prior to sampling, each tree was assessed visually for vertical distribution of pollen-bearing branches and for variation in the length of pollen shoots. Samples were taken prior to shedding when pollen buds were clearly visible. Trees were climbed and 19 to 21 pollen-bearing shoots (figure 1) per tree were severed individually from branches located throughout the crown; however,

Figure 1— *Pollen-bearing shoot of western white pine* (Pinus monticola *D. Don*).

no procedure was established to sample all shoot lengths equally. All shoots from a tree were placed in the same bag and stored in a refrigerator (2 ± 1 ºC) for no more than a month until examined. By tree, the following data were recorded for each shoot: shoot length (SL) (shoot base to base of terminal bud) in centimeters, pollen zone (PZ) (length of shoot occupied by pollen cones) in centimeters, and number of pollen cones (CONES). Analyses of variance (ANOVA) to test for differences among trees were conducted on raw data or on percentage data with and without arcsin transformation of the square root of percentage value per shoot (Zar 1984), and on CONES data following covariance removal of differences in SL, PZ, and both factors combined. Regressions to predict CONES were calculated from both SL and PZ, and for the percentage of the total shoot length that has pollen cones on it ("POL %" = 100% [PZ] ÷ SL), separately and combined, by tree and for all trees pooled. Regressions from separate trees were compared by covariance for the significance of differences in slope and intercept, using SAS GLM procedures and *t*-tests (SAS 1989).

Estimating sample size per tree. Sample sizes to determine mean PZ and mean CONES were calculated by tree using the following formula (Zar 1984):

$$n = (t_a^2 \text{ C } SD^2 \bullet F_b) \div D^2$$

where "t_a " = the tabular "*t*" = value for degrees of freedom "a" and type 1 error probability of 0.05, "SD" = the standard deviation of the parameter (for example, mean PZ), "F_b," = the probability of committing a type 2 error, set here at 0.10, and "D" = half of the acceptable limit sought. "D" was set at 0.5 cm for PZ and at approximately 25% of the mean of CONES by rounding up to the nearest full number.

Study *2. Estimating pollen quantity per bud.* Twenty pollen-bearing shoots per tree were collected by the same method from two more trees in the stand sampled for study 1 at the commencement of pollen shedding by each shoot. Each shoot was placed in a separate paper bag in the field, then placed in a warm environment indoors later the same day to continue pollen shedding. Each shoot was re-cut and the base placed immediately into tap water in a small vial in each bag. Water level was checked and replenished daily, as needed, during the study. Pollen was allowed to shed into the bag until tapping the shoot produced no more pollen. All pollen was sieved to remove impurities and poured into a graduated 10-ml flask. After the flask was tapped to loosen pollen adhering to the glass and to level the pollen surface, the volume was read to the nearest 0.5 ml. Finally, CONES per shoot was recorded. Linear regressions to predict pollen volume from CONES were calculated for each parent tree and for all data combined using SAS REG procedures (SAS 1989).

Results

Study 1. Summarized data of shoot attributes appear by tree in table 1. Trees are numbered in order of decreasing mean pollen cones per shoot. The following ranges were recorded for each attribute: SL, 1.6 to 14.8 cm; PZ, 0.7 to 5.8 cm; CONES, 5 to 60; and POL %, 17 to 85%. ANOVA found "tree" to be significant (P #0.05) for each parameter. Mean SL (trees 6 and 5) and mean PZ (trees 6 and 2) differed (P # 0.0001) by a factor greater than 2 (table 1). The lowest mean of POL % found was from tree 5, due mainly to its long shoots, whereas the highest value came from tree 2, due mainly to its high PZ (table 1).

Maximal and minimal values of pollen cones per shoot sampled were 60 buds from tree 2 and 5 buds from tree 10. The lowest mean of pollen cones per centimeter (CONES/cm) came from the tree with the longest shoots (number 5), but with a number of pollen cones per shoot near the mean. The most pollen cones per centimeter were found on tree 1, which had the highest mean value of pollen cones per shoot and a shoot length slightly below average.

Parent trees differed strongly (P # 0.0001) in CONES/cm PZ (table 1). The correlation between CONES and CONES/cm PZ was weak (R = 0.182) and not statistically significant.

Mean pollen buds per shoot before and after removal of SL and PZ effects by covariance, both separately and combined, are presented in table 2. Although all means were affected, the major difference following adjustment of the means is that tree 5, rather than tree 10, displayed the lowest adjusted value. It was consistently low following each adjustment, particularly when the effect of PZ was removed. Conversely, tree 1 ranked highest in all attributes but CONES/cm PZ, where it differed from tree 6 (table 1).

Linear regressions of CONES on shoot attributes were calculated. Greatest agreement (highest R^2) was found with PZ: all trees studied produced regressions significant at 0.0001 (table 3). Much-poorer trends were found with SL (only 5 of 10 regressions significant) and with POL % (3 of 10 significant) (results not shown). Both slopes and intercepts of CONES/cm PZ varied

Table *1-Descriptive of pollen-bearing shoots from 10 western white pine trees.*

	Shoot Length			Pollen zone(PZ)			% Pollen bearing per shoot (POL%)			Pollen Cones shoot (CONES)			CONES/cm			
Tree	Mean (cm)	SNK*	SD	Mean (cm)	SNK	SD	Mean	SNK	SD	Mean	SNK	SD	SL Mean	SNK	PZ Mean	SNK
1	4.31	b	1.66	2.49	a-c	0.88	58.8	ab	10.4	30.6	a	11.0	7.3	a	12.4	b
2	4.97	b	1.97	3.10	a	1.20	63.5	a	8.7	27.3	ab	11.4	5.7	bc	8.9	de
3	4.58	b	1.51	2.25	b-d	0.45	53.1	bc	14.6	23.4	bc	6.2	5.5	bc	10.3	cd
4	6.42	a	3.32	2.64	a-c	0.74	44.7	cd	9.6	22.2	bc	6.5	3.8	de	8.5	de
5	7.23	a	3.04	2.84	ab	0.75	42.0	d	9.9	20.9	b-d	6.6	3.1	a	7.4	e
6	3.05	b	0.73	1.47	e	0.39	48.9	b-d	8.9	20.7	b-d	7.0	6.9	ab	14.0	a
7	4.73	b	2.56	2.09	c-e	1.00	45.7	cd	9.3	20.3	cd	7.7	4.8	cd	10.5	cd
8	4.17	b	1.36	2.20	b-d	0.59	54.2	bc	7.8	18.9	cd	4.6	4.8	cd	8.8	de
9	3.35	b	1.48	1.58	a	0.71	48.9	b-d	12.4	16.6	cd	5.7	5.7	bc	11.5	bc
10	3.44	b	0.78	1.64	de	0.53	49.4	b-d	17.6	14.7	d	6.5	4.5	cd	8.9	de
Mean	4.62		1.84	2.23		0.72	50.9		10.9	21.6		7.3	5.2		10.1	
CV%	39.8			32.5			21.4			33.9			34.1		24.0	

* Means followed by the same letter(s) do not differ statistically (P>0.05) per Student-Newman-Keuls (SNK) test.

SD= standard deviation

Table 2— *Mean pollen cones per shoot before rind after covariance adjustment for shoot length polled-zone length and bout combined*

				Cones/shoot adjusted for:				
Tree	Cones /shoot	SNK*	SL length	*t* group†	PZ length	*t* group†	SL and PZ length	*t* group†
1	30.6	a	31.1	a	28.5	a	27.6	a
2	27.3	ab	26.7	b	20.3	c-a	18.7	d
3	23.4	be	23.5	b-d	23.3	b	23.2	b
4	22.2	be	19.0	a	19.0	d-g	20.0	cd
5	20.9	b-d	16.2	a	16.0	h	17.6	d
6	20.7	b-d	23.5	bc	26.8	a	26.7	a
7	20.3	cd	20.1	cd	21.5	b-d	22.0	bc
8	18.9	cd	19.7	c-a	19.2	c-g	18.7	d
9	16.6	cd	18.9	a	21.9	be	21.9	be
10	14.7	d	16.8	a 1	9.5	c-f	19.4	cd
Mean	21.6		21.6		21.6		21.6	
SD	8.7		6.8		4.5		4.3	
CV%								

* Means followed by the same letters) do not differ statistically (P > 0.05) according to the Student-Newman-Keuls (SNK) test.
† Means followed by the same letter(s) do not differ statistically (P > 0.05) for all-possible t-test comparisons among means.

Table 3– *Regression* of *pollen-cone number on pollen-zone length for ten western white pine trees*

Tree no.	No. of shoots	Slope Intercept (cones)	(cones/cm of PZ)	R‡*	Est. cones/ 2 cm PZ length,
1	20	4.34	10.54	0.727	25.4
2	21	1.00	8.48	0.786	18.0
3	20	-2.66	11.58	0.725	20.5
4	21	3.61	7.03	0.624	17.7
5	19	0.84	7.05	0.652	14.9
5	20	-1.28	14.93	0.688	28.6
7	20	8.58‡	5.63	0.534	19.8
8	20	5.24	6.22	0.627	17.7
9	20	6.58§	6.37	0.622	19.3
10	21	-2.19	10.29	0.715	18.4
Pooled	202	5.33	7.28	0.582	19.9

*Regressions all significant at P= 0.0002 or less.
†Estimated number of pollen buds on 2-cm pollen-zone length using table 3 regression by tree number. Pollen-zone length mean approximately 2 cm in table 1
‡ Tern significant at or below P= 0.01
§ Term significant at or below P=0.005

widely among trees. Comparisons of these regressions by tree showed that fifteen of 45 comparisons (not shown) differed significantly in slope and 24 of the 30 remaining comparisons differed in intercept. Analysis of data from all 10 trees pooled produced the following regression equation (regression eq. #1):

1. Pollen buds per shoot = 5.33 + 7.28 PZ (cm)
   $R^2 = 0.58$, P = 0.001.

Estimated number of pollen buds on a 2-cm PZ (approximately the mean BL in table 1), using the regression of pollen buds per cm of PZ by tree, appear by tree in table 3.

Combining SL and PZ as predictors produced a highly-significant (P = 0.01) regression for each tree (not shown), and increased mean R^2 from 0.670 to 0.732, an average of 8.1%G (maximum 27.5% [tree 9], minimum 0% [tree 3]).

Estimating sample sizes per tree. Minimal sample sizes calculated for CONES are smaller than for PZ (table 4). The range of estimated sample size per tree is more than two for CONES, whereas it is greater than five for PZ (table 4).

Study 2. T-tests indicated that the two trees sampled were very similar (P > 0.05) in both pollen cones and volume shed per shoot (table 5). An average shoot bore about 22 pollen cones and produced nearly 5 cm^3 of dry pollen. Comparison of their trends of pollen cm^3 per cone confirmed the similarity of the trees: neither trend had an intercept differing from zero, nor did their slopes differ (P# 0.64). Thus, the

Table 4— *Minimal sample sizes (shoots) require/d to attain specified limits for PZ length and pollen cones per shoot* by *tree*

Tree no.	Mean PZ length (cm)	No. of pollen-bearing shoots	Mean pollen cones/ shoot	No. of pollen-bearing shoots
1	2.49	31	30.6	21
2	3.10	53	27.3	28
3	2.25	11	23.4	14
4	2.64	24	22.2	14
5	2.84	24	20.9	20
6	1.47	9	20.7	22
7	2.09	39	20.3	25
8	2.20	17	18.9	12
9	1.58	22	16.6	16
10	1.64	14	14.7	27
Mean	2.28	24.4	21.6	19.9
SD	0.31	13.6	8.7	5.7

Note: PZ length = estimated within 0.5 cm of mean by tree: pollen cones/shoot =within 25% of mean number of pollen cones by tree.

following pooled regression equation (regression eq. #2)

2.Pollen-shed volume (cm^3) = 0.22 CONES; n=40
R^2 = 0.73, P = 0.001,

will estimate pollen yield per shoot from these trees accurately.

Discussion

Mean pollen cones per shoot from the western white pine trees in this study fall within the values for Himalayan pine *(P. griffithii*) (Konar and Ramchandani 1958) but well below those reported for Chir pine by Konar (1960).

Although no estimates of pollen yield per tree were made, factors influencing the yield per shoot are apparent in tables 1 and 2: trees differed in all shoot attributes, particularly PZ, CONES, and CONES/cm PZ. The importance of PZ on CONES is apparent in table 2 and in results from tree 6 in table 3. 1t should produce nearly twice as many pollen cones as tree 5 (28.6 vs. 14.9) from a 2-cm PZ (table 3), yet this difference in potential fecundity is reduced by the 2-fold difference between the trees in PZ (1.47 cm vs 2.84 cm), resulting in near-equal values: 20.7 pollen cones for tree 6 vs. 20.9 pollen buds for tree 5 (table 1). Thus, PZ is the most useful of these two variables to predict number of pollen cones on a shoot, and little is gained by measuring SL. The relative importance of CONES can be seen in table 2: the adjusted values in column 8 (adjusted for both SL and PZ) generally agree with those in column 6 (adjusted for only PZ). The weak correlation (R = 0.18) between pollen-cone number and pollen cones per centimeter of PZ suggests that differential elongation of shoots carrying a similar number of pollen cones might have occurred. Further study could produce more accurate estimates of cones from PZ, since the latter is the best predictor of pollen cones per shoot. Because the number of pollen cones per shoot for the two trees sampled for determination of cubic centimeters of pollen shed per cone are well within the bounds of confidence obtained for the 10 trees in study 1 (table 1), regression 2 could be applicable to them also, and perhaps to other western white pines, if shoots are collected at the appropriate time. However, Owens and Molder (1977) noted that "... the numbers of pollen cones varied considerably depending upon the year, the tree and the position of the branch on the tree." Sampling more trees and years will test the values presented here. **In the meantime a "rule of thumb" from this preliminary study is that 5 pollen cones will produce 1 cm^3 of pollen.**

The differences in regression of CONES on PZ among trees in study 1 indicate that inter-tree differences in allocation to reproduction per shoot may exist in white pine and may reflect genetic control, as found for loblolly pine by Schmidtling (1983). If so, white pine trees might differ in reproductive output and reproductive success, and perhaps in contribution to the seed crop (Roberds and others 1991). This will have an impact on the genetic balance in seed-orchard seed crops. Thus, depending on the accuracy wanted in estimates of pollen crop or in pollen volume to be derived, a separate regression to estimate CONES or

Table *5— Summary of pollen cones per shoot and pollen-shed volume (PSV) per shoot for two western white pine trees*

Tree	Pollen cones/shoot				PSV/shoot (cm^3)				Mean cm^3
No.	Min.	Max.	Mean	SD	Min	Max.	Mean	SD	pollen /bud
A	11	44	23.3	9.80	2.0	9.5	5.3	2.15	0.23
B	12	38	21.4	8.22	2.0	8.0	4.6	2.02	0.21
Mean			22.4	8.97			4.9	2.09	0.22
CV%			40.0				42.6		

cubic centimeters of pollen per cone may be needed for each seed-orchard clone, or a different sample size will be required to obtain a specified volume of pollen from each targeted tree or clone.

Applications

Estimating pollen crop per tree:

1. Determining or estimating the number of pollen cones per shoot (CONES): Collect approximately 30 pollen-bearing shoots from throughout the pollenbearing portion of a tree and determine mean and standard deviation of length of pollen zone (PZ) and CONES; calculate the regression of CONES on PZ (SAS 1989):

$$CONES = A + B(PZ) \qquad \text{REG 1}$$

2. Estimating volume of pollen shed per shoot: Using mean CONES [or the predicted value of CONES calculated from mean PS using REG 1 (step 1)] and regression eq. #2 from this paper, calculate extractable pollen volume per shoot, that is, extractable pollen (in cubic centimeters) = 0.22 (CONES).
3. Estimate the number of pollen-bearing shoots per tree according to Hoff and Coffen (1982).
4. Derive the estimated pollen crop per tree (in cubic centimeters) by multiplying the values from 2 and 3 above.

Collecting a specified volume of pollen per tree:

5. Determine mean PZ or CONES as in 1 above for the specified tree.
6. Estimate the pollen yield per shoot corresponding to mean or predicted CONES per shoot using REG 1 (step 1) and regression eq. #2 in step 2 above.
7. Divide the volume of pollen desired by the estimate of pollen per shoot from step 6 to obtain the minimal number of pollen shoots needed; collect them.
8. Determine the pollen volume per cone for your collections and compare to the mean of 0.22 cm^3 from this paper for your future use.

NB: To "ensure" collection of sufficient pollen 68% of the time, estimate the number of shoots to collect in the following way:

9. Subtract the standard deviation in CONES or PZ for your sample from the mean obtained in step 5. Then use that resulting value in step 6 and proceed through step 7, using a value of 0.125 cm^3 pollen per bud (derived as mean cm^3 pollen/shoot - SD cm^3 pollen/shoot [4.9 cm^3 - 2.1 cm^3 pollen/shoot] = 22.4 buds/shoot) (table 5).

NBB: To "guarantee" collection of sufficient pollen 95% of the time, use the mean of PZ minus 2 times standard deviation through steps 6 and 7. This should produce considerably more pollen than desired from some trees, permitting g storage of the excess for farther studies or for supplemental pollination in years with smell pollen crops on some clones.

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