Comments

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Editor-in-chief: Robert Mangold
Managing editor: Rebecca Nisley
Advisory editors: Robert Karrfalt, Thomas Landis, Clark Lantz, and Ronald Overton

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Cover: Transplanting plugs of sedge at the Lone Peak Nursery's constructed wetland (Draper, Utah) (photograph courtesy of the *Salt Lake Tribune).*

Back to the Future—Pest Management Without Methyl Bromide

The proposal by the Environmental Protection Agency (EPA) to ban the production and use of methyl bromide has been well publicized by the media, trade journals, and growers' organizations. Soil fumigation for the production of bareroot tree seedlings is but one of many uses of this important chemical. Production of agricultural commodities such as strawberries, tomatoes, peppers, and melons is also highly dependent on methyl bromide for eliminating soilborne pests in fields before planting. This fumigant is also used for postharvest treatment of stored fruits and nuts and for quarantine treatment of exported and imported fresh fruits and vegetables and other commodities. A ban on use of methyl bromide will have far-reaching impacts on agricultural production in the United States and on U.S. trade with foreign countries.

How did this situation develop? In 1991 an assessment made by the parties of the Montreal Protocol, an international treaty for the protection of earth's ozone layer, indicated that methyl bromide was one of the chemicals responsible for the depletion of the stratospheric ozone layer. Under terms of the agreement signed by the parties of the Montreal Protocol, methyl bromide was listed as a controlled substance to be phased out of production and use in a currently unspecified period of time. Amendments to the United States Clean Air Act of 1990 also mandate the phase out of Class I ozone-depleting chemicals, which includes methyl bromide. As a result, the EPA initiated a proposal to ban the production and use of methyl bromide by the year 2000. This proposal was published in the Federal Register in March 1993 and public hearings were held in April 1993.

The United States Department of Agriculture (USDA) was alerted early by the EPA that this ban was being considered. In response the USDA prepared a biological and economic assessment of the impact that the loss of methyl bromide would have on U.S. agriculture; this document was released in April 1993. The USDA also organized a 3-day workshop in Washington, DC, at the end of June to determine the available alternatives to methyl bromide and their attributes and to discuss the types of research that are needed to develop new alternatives. The workshop was divided into 9 working sessions based on commodity type. One session was devoted to the use of methyl bromide and its alternatives in the production of forest tree seedlings and ornamental crops. This session was attended by pest management specialists and researchers from various industries, universities, and State and Federal agencies. Workshop sessions were designed to facilitate discussions among participants. In preparation for the workshop we sent a questionnaire on soil fumigation practices to many nurseries that produce bareroot tree seedlings. The results of this survey helped the workshop participants to evaluate current soil fumigation practices, pest problems, and the availability and effectiveness of alternatives to methyl bromide in nurseries that produce tree seedlings. The survey also provided information from the nursery managers on research needs for the future. We thank all who took the time to participate in the survey and apologize to any individuals who we inadvertently missed in the mailing of the questionnaire.

Briefly, the results of the survey indicated that 86% of the nurseries that produce bareroot tree seedlings fumigate soils in preparation for planting to control soilborne diseases, insects, nematodes, and weeds. In the South 96% of the forest nurseries rely on soil fumigation; in the North and West about 80% of the nurseries fumigate nursery soils. Methyl bromide was the preferred fumigant; at least 80% of those who fumigate soils make use of this chemical and others still consider this chemical as an effective pest management tool even if they may not have used it recently. Dazomet (Basamid®) was used or tried by 51% of the nursery managers who fumigate nursery soils, but 73% of these managers found this compound to be less effective than methyl bromide. A small percentage of managers have used or tried other soil fumigants. Some have been satisfied with the performance of metham sodium (Vapam®, Busan® 1020, and Soil-Prep®), but Telone-C17® and Vorlex® were generally considered to be less effective than methyl bromide. A clear message was sent by many nursery managers that they are highly dependent upon methyl bromide to control soilborne nursery pests, and that current alternatives are either not available or not as effective as methyl bromide.

Workshop discussions in the session on forest tree and ornamental nurseries included (a) identification of the many major pest problems currently controlled by methyl bromide; (b) identification and attributes of current and potential alternatives to replace methyl bromide for the control of these pests; and (c) the prioritization of the research needs as a recommendation to the USDA. There was agreement among most participants that short-term (2 to 5 years) research efforts should focus on the development of integrated pest management systems that make maximum use of existing chemical, cultural, physical, and biological control practices. The focus of these short-term efforts should include determining application rates and the most effective application methods for other existing soil fumigants. There was strong but not universal agreement that nursery managers in the future will be forced to rely increasingly on nonchemical control methods. Many participants maintained that issues regarding environmental quality and concerns over public health and safety will only become greater with time. Thus, the workshop participants concluded that it is important that our long-range research focus on the development of biologically based integrated pest management (IPM) systems and their components. The goal of this research would be to eliminate the strong dependency on soil fumigants and other chemicals that adversely impact the environment. Therefore, long-term research in order of priority should include development and improvement of the following techniques:

1. Cultural pest control practices (cover crops, crop rotation, soil amendments, etc.)
2. Physical pest control practices (solarization, steam pasteurization, electronic heating, irradiation, trapping, etc.)
3. Chemical pest control practices (new, safer chemicals that target specific pest problems)
4. Biological pest control practices (introduction of biological control agents, suppressive soils, behavioral chemicals, soil amendments, etc.)
5. Genetic resistance to pests (through classical breeding systems or genetic engineering).

It is essential that research and application efforts in each of these areas be continued until newly developed practices are appropriately combined into the development of IPM systems that include effective combinations of existing and new cultural, physical, biological, and chemical control practices. Future IPM programs will require the application of a combination of control techniques at various times to achieve the level of control that we now obtain with methyl bromide. Methods to detect pest population levels and accurately forecast their impact will also be a necessity for future IPM programs of this type.

It is imperative that efforts to develop new effective IPM systems be supported by fundamental research on understanding the biology of pests and their hosts. Support for investigations on the biology and control of soil-borne pests in forest nurseries has continually eroded since the 1960's. Methyl bromide has been a highly effective soil fumigant, and our increasing reliance on this chemical for the last three decades has generally reduced the necessity for investigations on the biology and ecology of soil-borne pests. It is this kind of information that is now required to develop consistently effective, environmentally sound alternative means of pest control.

One thing seems to be clear: there is no currently available alternative to methyl bromide that is as effective against such a wide spectrum of soil-borne pests. Because of the great variation in climate, soils, pests, crops, and management systems, IPM programs will need to be designed for specific areas of the country and very possibly for individual nurseries. The development of these IPM programs will take close cooperation between nursery managers, extension specialists, and researchers. Universities and government agencies have a primary role in researching and developing alternative control methods. The private sector has a responsibility to assist in the development of application technology. It is essential that we all cooperate in the process of technology development and transfer.

Richard S. Smith, Jr.
Principal plant pathologist
Forest Insect and Disease Research Staff
USDA Forest Service, Washington, DC

Stephen W. Fraedrich
Plant pathologist
Southeastern Forest Experiment Station
USDA Forest Service, Olustee, Florida

Note: Our concept of this editorial space is that it should be a place to publish opinions and ideas relating to the reforestation profession. We invite you to submit ideas for commentaries. The views expressed here are solely those of the author(s) and do not necessarily reflect those of the *Tree Planters' Notes* editorial board, the Forest Service, or the U.S. Department of Agriculture.

Using a Constructed Wetland to Treat Waste Water and Propagate Wetland Species

Glenn Beagle and John Justin

Coordinator and nursery coordinator, Utah Division of State Lands and Forestry
Lone Peak Conservation Center, Draper, Utah

Constructed wetland ponds at Lone Peak State Nursery near Salt Lake City, Utah, produce herbaceous plants for both wetland restoration projects and creation of new wetlands in agricultural, urban, and industrial applications. In response to the new demands for specialized wetland plant materials, the nursery developed partnerships with both private businesses and government agencies to develop a constructed wetland system. This innovative system not only catches and treats agricultural runoff by physical, chemical, and biological processes from the container nursery, it also serves as a propagation system for wetland plants such as sedges (Carex spp.), *rushes* (Juneus spp.), *spikerushes* (Eleocharis spp.), *and bulrushes* (Seirpus spp.). *An additional benefit of this project is that new vegetative and seed propagation techniques are being developed and made available to other nurseries.* Tree Planters' Notes 44(3): 93-97; 1993

The demand for riparian plants is increasing rapidly, especially for nonwoody species. The national policy of "no net loss of wetlands" has resulted in many mitigation projects that require wetland plants. Water quality improvement projects are also creating a market for these plants. Lone Peak State Nursery (operated by the Utah Division of State Lands and Forestry near Salt Lake City, Utah) recognized these trends in 1991 and began looking at various economical methods of producing wetland species such as sedges *(Carex spp.)*, rushes *(Juncus spp.)*, bulrushes *(Scirpus* spp.), and spikerushes *(Eleocharis spp.)*.

Another difficulty facing many nurseries today is the need to control point-source pollution from greenhouse operations. In the near future, many nurseries will have to address their runoff pollution problems because of stricter enforcement of current laws and passage of tougher new laws.

Lone Peak State Nursery has developed an innovative constructed wetland system that deals with nonpoint-source pollution while providing an environment for propagating obligate wetland plant species (figure 1). Obligate wetland species almost always (> 99%) grow in wetlands under natural conditions (Reed 1988). Formerly, the nursery's greenhouse runoff leached into a bareroot production field and eventually drained into an irrigation canal below the nursery. The affected field experienced a high incidence of disease and seedling mortality because the soil was saturated and had high nitrate levels.

Figure *1-Constructed wetland production ponds of sedges* (Carex) *and rushes (Juncus) species. The Lone Peak Nursery's bareroot seedling fields can be seen in the background, and the]or dan River irrigation canal can be seen in the upper right.*

We decided that a water collection system below the greenhouse should capture the runoff and take it to collection ponds where it could be treated. Treatment of waste water by wetland systems can be characterized by the removal of dissolved pollutants, nitrates, phosphates, suspended solids, trace metals, and pathogens by physical, chemical, and biological processes. Treatment mechanisms of wetland systems include sedimentation, filtration, chemical precipitation, absorption, microbial interactions, and uptake by vegetation (Watson et al. 1988).

At about the same time, we came up with the idea of propagating wetland plants in these ponds. The Washoe State Nursery of the Nevada Division of Forestry was collecting "meadow plugs" of a mixture of wetland species and propagating them in containers. We decided to modify Nevada's system so that we could isolate individual species and propagate them separately.

We developed the following objectives for the proposed constructed wetland project:

1. Improve the water quality of greenhouse waste water before it leaves the Lone Peak Nursery property.
2. Develop commercial methods to propagate five obligate wetland species.
3. Produce and harvest seed from four selected wetland plant species.
4. Generate sufficient revenue from wetland plant sales to make the program self-supporting.

Figure *2-Smallest pond during construction, showing subsurface drain system and 30-mil plastic liner.*

Search for Political and Financial Support

Because the nursery did not have the funding for such a large project, we needed to generate financial support for our constructed wetland. The Utah Department of Agriculture (UDA) was a strong advocate for the project. Because it could benefit from a supply of wetland plants for agricultural filter strips, the UDA provided initial funding and collaborated with the USDA Soil Conservation Service (SCS) to design a collection and water storage system to Lone Peak's operational specifications. Utah Power, a private utility company that had begun using native plant communities to improve water quality and soil stability, saw the long-term benefits of creating a commercial source of wetland plants and provided a major construction grant. The USDA Forest Service assisted the project by providing Cooperative Forestry funding. The nursery also received political support from numerous private and government cooperators that were potential users of wetland plants.

Design and Construction of Runoff Collection System and Treatment Ponds

Our constructed wetland was designed as four ponds lined with a 30-mil plastic membrane with inlets for runoff and field irrigation water (figure 2). We wanted a sealed system to prevent waste water from leaching out of the ponds, control water levels, and allow monitoring of pollutant levels in water drained from the ponds. Each pond has a French drain--a trench filled with rock--for adjusting the water table depth and draining the water for plant harvesting operations.

A mixture of sandy loam topsoil and washed concrete sand was placed in the ponds to a depth of 2.5 feet (.76 m). This soil mix was selected to prevent introduction of weed seeds from nursery soils and to provide a coarse-textured, easily drained soil.

Water enters the pond in two ways. The primary source is non-point-source water from upslope and greenhouse runoff that is captured in a French drain oriented along the contour below the greenhouse, drains into a settling box, and is piped underground to the ponds (figure 3). Additional water enters the ponds via the field irrigation system, which is connected to the underground drains and pond inlet piping. This feature has proven valuable for the following reasons: runoff sediment accumulates quickly in the underground pipes and the entire system can be flushed under pressure with irrigation water. Also, during dry summer months it has been necessary to supplement runoff with irrigation water to maintain proper water levels in the ponds.

The constructed wetland design has been in use for 1.5 years with very few problems. The only change in design we recommend is reducing the top width of the pond dikes from 10 feet (3.05 m) to 2 feet (.61 m) and the height of the pond dikes from 5 feet (1.5 m) to 3 feet (.9 m). Our dikes were overdesigned for the project's needs, and significant construction savings could be realized with smaller dikes. If local topography allows, complete elimination of the dikes would be extremely economical. Digging shallow depressions with a bulldozer may be all that is necessary.

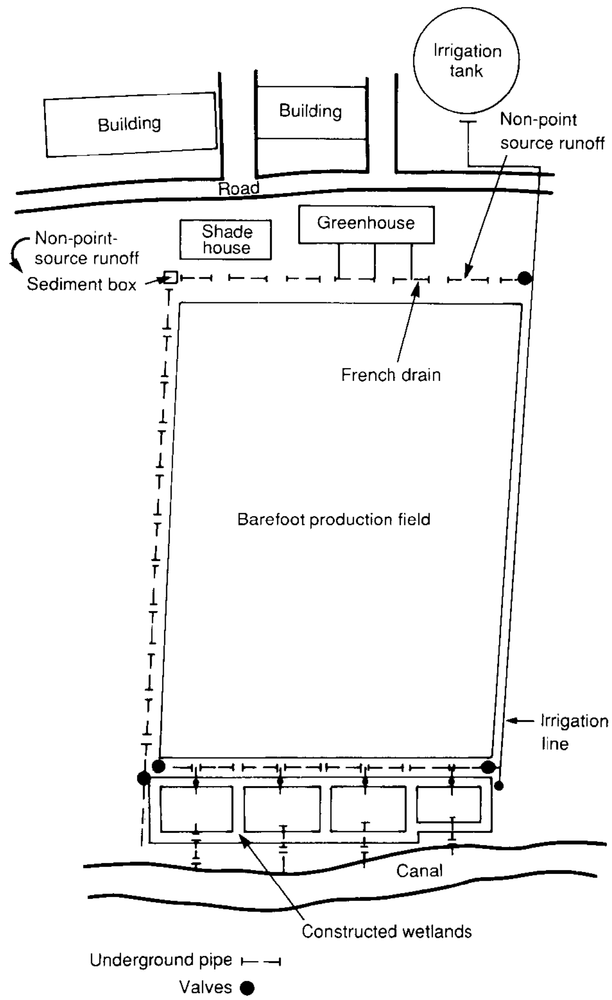

Figure *3-Overhead diagram of the constructed wetland project showing the collection area below the greenhouse complex and the location of the ponds.*

Vegetative Propagation System for Wetland Plants

The propagation system developed for the ponds is designed to vegetatively produce container seedlings ("plugs") of individual wetland plant species. The design minimizes field collection costs, transplanting losses, and associated high labor costs.

The initial stock plants are collected by nursery crews from local native wetland communities. Collected plant materials should be handled like bareroot tree seedlings because they do not store well and must be replanted quickly. Cold storage of plants for longer than 2 to 3 days appears to reduce transplant success. The wild collections are first potted and grown to maturity so that the identity of the different species can be verified.

When the plants are correctly identified, single species are planted in each of the four ponds. Nebraska sedge *(Carex nebraskaensis),* beaked sedge *(Carex rostrata),* baltic rush *(funcus balticus),* and creeping spikerush *(Eleocharis palustris)* are currently growing in the ponds. Hardstem bulrush *(Scirpus acutus),* which is difficult to handle vegetatively because of its size and form, was not planted in the ponds.

The pond soil is saturated to soften it and then the ponds are planted with plugs containing 2 to 3 shoots on a 1-foot by 1-foot (.3-m by .3-m) spacing (figure 4). The plants spread vigorously throughout the soil by vegetative reproduction . After 9 months, when the ponds contain approximately 20 to 25 shoots per square foot, 40% of the surface area is harvested (figure 5). The coarse-textured pond soil easily falls away from plant roots during harvesting, which limits soil loss. Individual shoots and rhizomes are divided out and potted into 10-cubic-inch (163-cm3) Ray Leach super cells or 29-cubic-inch (475-cm3) D-pots. Pond soil is replaced after each harvest to fill in holes and level the soil surface.

The container plants are held in propagation areas-shadehouses or open growing areas-where they are exposed to full sunlight for 1 to 2 months. When multiple shoots appear, they are divided into single shoots, repotted, and returned to the propagation area. Several divisions occur each growing season, with each division increasing the number of plugs by about 50% (figure 5).

Figure *4-Work crew planting Nebraska sedge* (Carex nebraskaensis) *on 1-foot (.3-m) centers.*

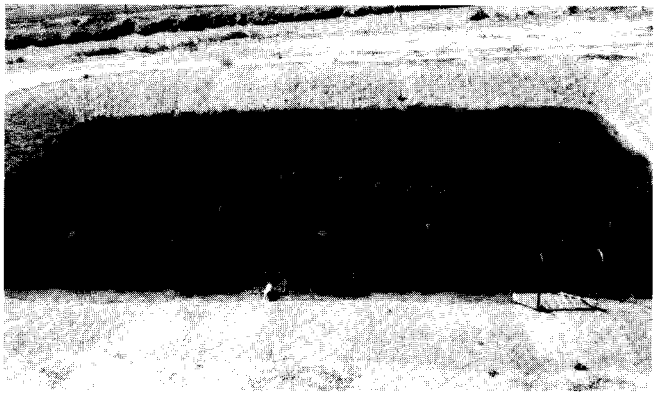

Figure *5-Constructed wetland ponds are harvested once a season, and then these plants are transplanted to containers and propagated by division 2 to 3 more times, with a potential 50% increase each time.*

This propagation system has proven satisfactory, but we are still experimenting with better production methods for wetland plants:

1. Trials have been conducted to determine the optimum growth container for sedge species. Fourinch-deep (10-crn-deep) geranium pots, 29-cubicinch D-pots, and 10-cubic-inch Ray Leach tubes have been tested. The geranium pots appear to allow the greatest rhizome development because they have the largest surface area. The D-pots and geranium pots are used for initial potting. Ray Leach tubes are used at the final division.
2. Managing the water levels in the ponds is very important for culturing wetland plants, and growth rates varied significantly between different species. Our experience and information supplied by the SCS Aberdeen Plant Materials Center indicates that the optimal water level for beaked sedge is at the soil surface; for Nebraska sedge, it is 1 to 2 inches (2.5 to 5 cm) above the soil surface; for creeping spikerush, it is 3 to 4 inches above the soil surface; and for baltic rush, it is 1 to 2 inches below the soil surface.
3. Labor costs can account for a large portion of the cost of wetland plant production. Field collection, transplanting, and plug division all require many worker-hours. Any methods that save labor should be considered. The construction of a wetland on nursery grounds allows on-site collection of plants, thus reducing overall production costs. Harvesting plants from dense, wet stands in heavy soils is labor intensive, and so we are currently evaluating several tools to ease this process.

Limitations of the Current Design of the Constructed Wetland

Soon after our constructed wetland was operational, it became evident that precisely monitoring the system would be difficult. The French drain collection system below the greenhouse complex is not completely effective, and all greenhouse runoff is not captured. A better design would have a direct drainpipe from greenhouse floor drains to the treatment ponds.

Testing for different dissolved pollutants and analyzing the efficiency of the treatment ponds proved to be extremely expensive. Chemical analysis for single pollutants, especially pesticides, can cost several hundred dollars apiece. Another complication to monitoring the water quality was the introduction of the non-pointsource water to the system (figure 3). The runoff from the greenhouse and shadehouse is actually a minor component as compared to the non-point-source water and so precise monitoring is difficult with this system.

Propagation in the constructed wetland ponds required greater amounts of water than our one greenhouse operation provided. To maintain the proper water levels for the various species over the growing season, substantial amounts of water had to be added to the ponds from the field irrigation lines.

Future Needs and Opportunities

Need for more growing area. The demand for wetland plants for reclamation projects has exceeded our current vegetative production capabilities. Mitigation and conservation uses of wetlands for water treatment projects have created a substantial demand for reasonably priced wetland plants. Much of the nursery's small greenhouse is already needed for routine seedling production, and so additional space is required to meet the demand for the wetland program. The changeover to seed propagation of wetland plants will also require more greenhouse space. A new greenhouse with a closed irrigation system would also allow the monitoring of nutrient uptake of individual plant species and microbial activity responsible for improving water quality.

Seed propagation. The potential exists to produce some species of wetland plants from seed. Compared to vegetative means, seed propagation offers several advantages such as lower field collection costs, less growing area, and a shortened production cycle. Current obstacles to seed propagation include lack of knowledge on pre-germination treatments and seed storage viability, and limited availability of local seed sources. Lone Peak's seed research has been concentrated on the propagation of hardstem bulrush (Scirpus acutus) and alkalai bulrush (Scirpus maritimus). Initial plans called for planting hardstem bulrush in one constructed wetland pond. After working with this species, it was apparent that vegetative propagation was not practical because of the plants' large size. Propagation of sedges and rushes from seed may also be advantageous because of the high labor costs of dividing and transplanting plugs. We are currently exchanging information on pre-germination seed treatments for wetland species with the USDA Soil Conservation Service's Aberdeen Plant Materials Center and Nancy Shaw of the USDA Forest Service's Intermountain Experiment Station.

Some of the existing constructed wetland ponds could be converted to seed production areas to provide a known seed source of single species. The ponds would continue to be a component for water treatment of our existing greenhouse and non-point-source pollution.

Technology transfer. The production of wetland

Plants is a newly emerging aspect of the forest and conservation nursery field. The constructed wetland project was developed to produce salable plants and develop practical propagation techniques. The resulting information and technology may be used by other tion needs. Lone Peak State Nursery could supply plantlets or seed from our constructed wetland for private nursery propagation.

Many unknowns still exist in propagating wetland plants vegetatively and from seed. Development of seed collection, processing, and germination techniques may yield more economical production methods. Our wetland plant production will continue to be a cooperative project among Federal, State, and private organizations. For more specific information on this project, contact:

Glenn Beagle, Coordinator
Lone Peak State Forest Nursery
14650 Prison Road
Draper, UT 84020
Tel: (801) 571-0900
FAX: (801) 571-0468

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Aspen Seed Collection and Extraction

Martin Y. P. Fung and Barbara A. Hamel

Reclamation research associate and greenhouse technologist, Syncrude Canada Ltd., Fort McMurray, Alberta, Canada

Aspen (Populus tremuloides Michx.) seeds can be collected when about one-third of the capsules within a cluster have partially opened but before the cotton begins to well out. For optimum viability, the seeds must be extracted within 1 week of collection. Seeds contained in sealed jars and stored at -20 /C remained viable after 2 years. Tree Planters' Notes 44(3): 98-100; 1993.

Until a decade ago, aspen (*Populus tremuloides* Michx.) was considered a weed tree. Dramatic increases in its utilization by the pulpwood and lumber industries have brought the species recognition as commercially important. Consequently, interest in aspen ecology, management, and regeneration has escalated significantly in recent years.

Although aspen regenerates *very* effectively by root suckering, it can also be propagated readily from seeds. This method of forest regeneration is important to help preserve genetic variability and promote widespread dissemination and colonization of new areas through wind-dispersed seeds. Also, propagation from seeds is still the most economical method for large-scale seedling production in greenhouses. At the Syncrude oil sands mining site in Fort McMurray, Alberta, aspen makes up 50% of the 250,000 tree seedlings grown and planted annually for the reclamation of disturbed lands.

Aspen Fruits

Aspen is dioecious, with flowers borne on catkins. Flowering occurs in spring just before leaf emergence. The fruits are individual solitary capsules that are borne on the female catkins. Before the leaves are fully expanded, the capsules split into two parts to expose the tiny tufted seeds for wind dispersal.

Good seeds are derived from mature capsules that are plump and rounded at the base and have erect points (Schier et al. 1985). Capsules that are somewhat flattened and taper rather evenly from base to point do not contain viable seeds.

Seed Collection

The time of flowering is not a reliable predictor for scheduling seed collection (Schier et al. 1985). The exact time of seed maturity varies slightly from year to year, depending on sites, age of trees, and local weather conditions. Precise timing of seed collection is crucial. The goal is to harvest seeds as close to maturity as possible. If the fruits are picked prematurely, the seeds do not ripen and viability is poor (Schreiner 1974). On the other hand, aspen seeds dehisce rapidly upon maturation, and one windy day can disperse the whole crop. Therefore, intensive monitoring of the seed maturation progress is critical because the range of appropriate collection time may be as narrow as 48 hours.

At Syncrude, we begin collecting seeds when about one-third of the capsules within a cluster have split at the point, but before the cotton begins to well out (figure 1). In Fort McMurray (57/ 02' N, 111/ 36' W), this occurs between mid to late May. The seeds collected at this stage will mature fully and viability usu ally approaches 100%.

The capsules can be harvested by either chopping down branches laden with catkins or felling the entire tree. Next, we recommend dislodging the capsules from the catkins because the stems will interfere with the seed extraction process. This is accomplished by grasping the catkins with one hand, starting at the top, and gently pulling downwards along the stem. Position a container below to collect the capsules as they drop.

When picking is completed, take the capsules to a shelter and place them in large shallow tubs for further ripening. Spread the capsules in single layer to ensure proper ventilation to prevent mold infestation. Place a plastic mesh over the tubs and store at room temperature, away from full sunlight, for 3 to 5 days. By then the tubs will be filled with cotton, and seed extraction must begin immediately.

Seed Extraction

The following seed extraction procedure has been used by Syncrude with consistent success:

Assemble a set of 30-cm diameter sieves (as shown in figure 2), starting with a pan at the bottom followed in ascending order by 60-, 40-, 20- and 10-mesh sieves. Lift up the top sieve and fill the 20-mesh sieve with cotton containing seeds. Reposition the top (10-mesh) sieve.

Figure 1 - *Aspen capsules ready for picking.*

Attach a vacuum cleaner hose to the posterior socket of the canister and blow at the cotton through the top sieve with a side-to-side motion followed occasionally by a circular motion until most of the aspen seeds have been dislodged. The air stream velocity can be adjusted either with the vacuum speed control mechanism or simply by applying adhesive tape around the nozzle to constrict the opening. It is not necessary to extract all the seeds because those seeds

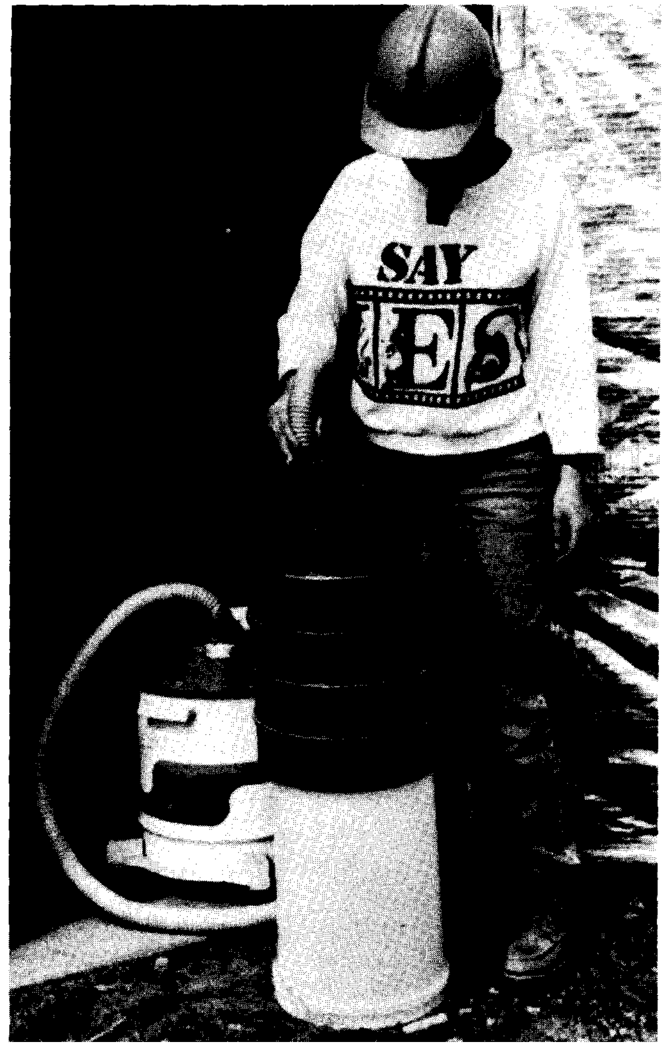

Figure 2 - *Extracting aspen seeds using sieves and a vacuum cleaner.*

that are difficult to dislodge are usually non-viable. Seeds will gather in the 60- and 40-mesh sieves. However, the seeds trapped in the 40-mesh are generally superior in terms of cleanliness, size uniformity, and viability.

Even though no seed will be found in the bottom pan, it is advisable to have it in place because it redirects the air stream upwards, causing the cotton to tumble, and thus facilitates seed separation. In addition, the pan eliminates dust turbulence during the extraction process.

Seed Viability and Storage

Aspen seeds deteriorate rapidly upon maturity. Thus, it is imperative that the seeds are extracted and stored within 1 week of collection, after which the viability declines sharply. Our tests showed that seed viability had greatly diminished when the seeds were left in the tubs for 4 weeks before being extracted.

After extraction, no further seed cleaning or drying is necessary. Immediately decant the seeds into suitable jars, seal tightly, and store at -20 /C. By using this method, our aspen seeds lasted for at least 2 years without significant loss of viability.

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Loblolly Tree Seed Collection System

Dick Hallman

Project leader, USDA Forest Service, Missoula Technology and Development Center, Missoula, Montana

A net retrieval tree seed collection system for loblolly pine (Pinus taeda L.) *has been designed and built by Missoula Technology and Development Center (*MTDC*) engineers. The system combines polypropylene netting that covers the orchard floor to collect seeds, a self-powered retrieval mechanism that rolls and unrolls the netting, and a conveyor that delivers the seed to a separator where it is separated from pine straw and other material. The system can produce seed at a reduced cost while enhancing workers' safety.* Tree Planters' Notes 44(3):101-104;1993.

Engineers at the Missoula Technology and Development Center (MTDC) in Missoula, Montana; the Georgia Forestry Commission in Macon, Georgia; and the USDA Forest Service's Southern Region, headquartered in Atlanta, Georgia, designed a mechanized net retrieval and seed collection system for loblolly pine seed orchards that has made seed harvesting safe and simple. The system consists of a net, a self-powered retrieval system, a conveyor, and a seed separator. The system has been used successfully in southern seed orchards to gather loblolly pine seed for more than 10 years. However, the results of the project are being reported here for the first time. A complete set of drawings for assembling the system and specifications for purchasing the appropriate netting and associated support products have recently been completed and are now available.

Background

Harvesting seed in orchards has traditionally been done by hand. Mature unopened cones are picked from the trees by workers and processed to extract the seed. Because most cones are in the top half of a tree's crown, manually removing these pine cones requires ladders, power platforms, or aerial lifts. Typically, pickers work 30 to 40 feet (9.1 to 12.2 m) above the ground, and the specialized equipment necessary for this operation is utilized for only 4 to 6 weeks a year.

Of the six economically important pine species in the southern United States, loblolly pine *(Pinus taeda* (L.)) has become a popular choice for reforestation throughout the Southeast. Its cones are the most difficult to harvest because they firmly anchor themselves to the tree branch and are particularly hard to dislodge by hand. Manual collection methods cannot keep up with the demand for superior loblolly seed. In addition, workers collecting mature cones frequently break off immature first-year conelets, which reduces the seed crop in the following year. Tree shakers have been tried for dislodging mature loblolly cones, but they also can damage trees.

GFC Netting System

In the early 1970's, the Georgia Forestry Commission began work on a system to harvest loblolly seeds more effectively. They completely covered the orchard floor with polypropylene netting material that caught fallen seed, "pine straw," and debris coming from the trees. Their system allowed the cones to mature naturally on the trees, so that cones could open fully and drop their seeds naturally onto the net spread on the orchard floor. A tree shaker then shook all the remaining seeds from the cones onto the netting. The shaking process deposited tons of pine straw on the netting.

Netting was initially placed between the tree rows, overlapped, and stapled. When retrieving seeds, the stapled edges of the netting were released, and the netting was lifted to separate the grass that had grown through it. This process pushed the material toward the center of the net. Using a tractor, the netting material was folded back on itself and pulled until the debris, seed, and pine straw were all deposited at the end of the row. The process was repeated for each roll of netting.

The netting was then spread out and re-rolled for storage. A modified peanut combine was moved into place to separate the seed from the pine straw and other unwanted material. This semi-clean seed was then transported to a seed processing facility where it was conventionally cleaned and prepared for storage. This collection operation usually required a crew of four, a tractor, and a tree shaker.

MTDC Retrieval/Collection System

Working with this concept, MTDC engineers designed a prototype net system for collecting and retrieving tree seed. This system combines the original Georgia Forestry Commission netting concept with a self-powered retrieval mechanism and a seed separator that simplifies the collection process.

With MTDC's system, the net retrieval/seed separator units are positioned at the end of a netting row (figure 1). The edges of the netting are released from the adjacent nets and lifted to free the material from any grass growing up through the fabric. The netting is attached to the aluminum core on the retrieval unit and is reeled in under power (figure 2). The speed of retrieval can be varied based on the amount of material on the net.

Figure 1-The MTDC's net retrieval-seed separator system positioned at the end of a netting row.

Figure 2—*Reeling in the netting under power.*

Figure 3-Close-up of the seed separator sorting the seeds and needles.

As the net is being reeled in, the seed and other material pass over a reversing roll and drop onto the conveyor. The conveyor transports the material to the seed separator. The seed separator cleans the seed and prepares it for extractory processing (figure 3).

The large amount of clean pine straw that is produced is an added benefit. Orchard pine straw is a prime-quality mulch that does not contain the weed seed and other debris normally found in straw bales; there is a ready market for this product.

Field Tests

The system was extensively tested at three sites: the Francis Marion Orchard in South Carolina; the Erambert Orchard in Mississippi; and the Stuart Orchard in Louisiana. Approximately 4,529 pounds (2054.4 kg) of loblolly pine seed were collected from 216 acres (87.4 ha) at the three locations with the net retrieval system. In 1984, James L. McConnell and Jerry L. Edwards of the Southern Region produced an economic study of the system. Their report included the following information on equipment and costs:

Net: Polypropylene plastic; 16.5 feet (5 m) wide by a variable length (600 feet or 183 m average); weave count = 6 x 8 per square inch; expected life = 10 years. Netting should be purchased according to Forest Service specifications.

Cost: $316,214 (1982 price) for three orchards (350 acres or 141.7 ha).

Core: Aluminum alloy 6063-T6; 4-inch outside dimension (10 cm) by 17 feet, 4 inches long (5.3 m); expected life = 20 years.
Net retrieval equipment: Net retrieval seed collection machine, netting transport trailer with crane, and tractor-mounted tree shaker; expected life = 20 years. The retrieval seed collection machine must be constructed according to the specifications of Forest Service drawings. The transport trailer, crane, and tractor-mounted tree shaker are available commercially.

Amortized annual fixed costs:

Item	Expected life	Annual cost
Netting	10 years	$31,621
Cores	20 years	$ 702
Retrieval equipment	20 years	$ 7,224
Annual fixed cost		$39,547

Variable costs:
$48,575 (labor, general equipment usage)

Total cost of net collection in 1984:

Category	Total cost (216 acres)	Cost per acre
Variable costs	$48,575	$225
Fixed costs	$39,547	$183
Total cost	$88,122	$408

Cone Collection

Seed production was spotty. Atlantic Coast collections were light; Gulf Coast collections were good to heavy. Loblolly yield was 1.43 pounds (0.7 kg) of seed per bushel of cones. The netting system collected 4,529 pounds (2054.4 kg) of clean seed. This is equivalent to the seed yield from 3,167 bushels of cones.

The collection of 3,167 bushels of cones by contract or force account (using Forest Service workers) would have cost $33 per bushel. The total cost would have been $104,511.

Cost breakdown:

Collection	$30
Drying and extraction	$ 2
Transport to extractory	$ 1
Total Cost	$33

Comparison of costs:

	Total costs	Cost per pound of seed
Cone collection (hand)	$104,511	$23.07
Net collection	$ 88,122	$19.45
Cost Saving	$ 16,389	$ 3.62

Results

The cost of the net seed collection system will be greatly affected by the volume of seed available. Because of high initial equipment costs, a small or young low-yield orchard will not find the net retrieval system an economical alternative to cone collection. In a large-volume, mature seed orchard, however, the net retrieval tree seed collection system can produce seed at a reduced cost while enhancing worker safety and eliminating the need for expensive power platforms or bucket trucks (figure 4). Seven systems are currently in use: two in private orchards; four in southeastern U.S. Federal and State orchards, and one in a European orchard.

Figure 4 - *Workers putting away the net retrieval-seed separator system. They find it easy to use and safe.*

Drawings

During development and testing, the towed prototype system was modified and refined by MTDC engineers working with material manufacturers and Southern Region personnel. A self-propelled model was developed. MTDC has recently completed fabrication drawings for the self-propelled net retrieval tree seed collection system. Ask for *Orchard Seed Harvester, MTDC Drawing 709.*

Netting Specification

MTDC, in cooperation with the Southern Region, has also produced a standard specification for netting material. Currently, Amoco Fabrics and Fiber Company is the only company with a loom wide enough to produce the needed material. Contact them at:

Amoco Fabrics and Fiber Company
A Division of American Oil Company
900 Circle 75 Parkway, Suite 550
Atlanta, GA 30339
Calvin Burgess (404) 956-9025

The netting material is commonly referred to as "carpet backing." The polypropylene plastic is also available in both a weave and fused net. Netting material must fully meet the following specifications:

1. Basic material. The retrieval netting fabric shall be manufactured from polypropylene plastic in continuous length. Splices, welds, or sewn together pieces shall not be permitted.

2. Dimensions. Retrieval netting fabric shall be delivered in rolls measuring 1,000 feet (304.6 m) long by 16.5 feet (5.0 m) wide.

3. Color. Color shall be black.

4. Amoco calls its product "Seed Catcher Net," item 8805. Weave count is 6 x 10. Yarns per inch shall be six in the warp direction and ten in the filling direction.

5. Weight. Weight shall be 2.1 ounces/square yard minimum and 3.0 ounces/square yard maximim.

6. Tensile strength. Tensile strength shall be 60 pounds minimum in the warp direction and 60 pounds minimum in the filling direction when tested in accordance with ASTM D 1682, Grab tensile test.

7. Burst strength. Burst strength shall be 175 pounds minimum per square inch when tested in accordance with ASTM D 751.

8. Yarn stability. Yarn stability shall be 250 g minimum when tested in the following manner:

Test apparatus: 500-g capacity pull spring scale graduated in 25-g increments.

Test method:

A. Spread sample netting on table.
B. Take the pull spring balance and hook a double end about 15 inches (38.1 cm) from the top and bottom selvage edges of the netting.
C. Pull the double end until it breaks its bond and touches the adjacent end. At this point the balance should be read to the nearest 25 g.
D. Take three readings from each side of the fabric, spacing each reading according to the lengths of the sample.
E. Average and record readings.

9. Cores. All cores shall be continuous in 17 feet, 4 inch (5.3 m) lengths. Cores shall have a 4-inch (10.1 cm) minimum inside diameter.

10. Outdoors wearing. The plastic fabric netting shall exhibit a minimum of 70% retention of properties after 400 hours in a weatherometer when tested in accordance with Federal Standard 191A, Method 5804.

11. Selvage edge. Selvage shall be a rninimun of 1/4 inch (0.6 cm) for each edge.

For further information on the loblolly tree seed collection system, contact:

Dick Hallman
USDA Forest Service
Missoula Technology & Development Center
Building 1, Fort Missoula
Missoula, MT 59801
(406) 329-3946

Photoperiod Extension With Two Types of Light Sources: Effects on Growth and Development of Conifer Species

Steven K. Omi and Kent L. Eggleston

Forester and horticulturist. USDA Forest Service. Coeur d'Alene Nursery. Coeur d'Alene. Idaho

Growth and development of seven conifer species were evaluated using two light sources and five light environments. One source was incandescent light, which was the standard system used at the nursery. The other source was a high-pressure sodium lamp mounted inside an oscillating parabolic mirror, a system that has not been tested on an operational basis. Morphological response to the different light treatments was species dependent; however, generally all treatments produced seedlings that met our regional morphological standards for planting. With only a few exceptions, crop uniformity was not significantly altered by the new oscillating light system, relative to the standard treatment. Tree Planters' Notes 44(3): 105-112; 1993.

Extension of photoperiod for producing container seedlings is a common tool in North American nurseries. Photoperiod extension is especially important for growing northern-latitude and high-elevation ecotypes and species at southern latitudes. Height growth can cease early in the growing season if supplemental lighting is not provided (Arnott 1974). A pigment, phytochrome, is responsible for controlling the physiological responses to photoperiod. When exposed to red light (660 nm), phytochrome is converted to an active form that inhibits the initiation of dormancy. Far red light (735 nm), or absence of light, converts the active to the inactive form. The active form of phytochrome not only prevents dormancy but, in the right ratio with the inactive form, can also inhibit stem elongation. Therefore, it becomes important for nursery managers to manipulate light environments such that dormancy is prevented while height growth is promoted.

Photoperiod can be extended by continuously providing light (for example, before sunrise or after sunset) or by interrupting the dark period with intermittent lighting. Intermittent lighting is generally preferred because of growth inhibition caused by continuous red light (Landis et al. 1992). The light intensity required for promoting photoperiod effects is much less than that required to promote photosynthesis. As a general rule, Landis et al. (1992) recommended that the critical minimum light intensity should be at least 8 µmol m^{-2} s^{-1}. However, for mountain hemlock *(Tsuga mertensiana* (Bong.) Carr.), Pacific silver fir *(Abies amabilis* Dougl. ex Forbes), Engelmann spruce *(Picea engelmannii* Parry ex Engelm.), and white spruce *(Picea glauca* (Moench) *Voss),* the critical minimum light intensity was found to be as low as 0.4 to 1.6 Rmol m^{-2} s^{-1} under a continuous 24-hr photoperiod (Arnott 1979).

The duration of light during the dark period is another factor that must be controlled. As long as a dark period is less than 30 minutes, the lights can be on as little as 3% of the time (Tinus and McDonald 1979). Two minutes of light every 30 minutes was the most effective cycle for promoting height growth and plant weight for 4 provenances of white and Engelmann spruce (Arnott 1979).

The Forest Service's Coeur d'Alene Nursery has traditionally used incandescent bulbs to provide intermittent lighting during the dark period. This light source is the most widely used source for photoperiodic lighting in U.S. and Canadian nurseries (Landis et al. 1992). Incandescent bulbs have simple circuitry, have high light output relative to the size of the bulb, are cheap to install, and can be used intermittently with out loss of bulb life (Bickford and Dunn 1972, Landis et al. 1992). However, incandescent lamps have low light output per input watt of energy, generate a lot of heat, are critically affected by voltage variations, and require frequent bulb replacement (Bickford and Dunn 1972).

Another source for light that has increased in popularity is the high-pressure sodium light, now used for about 27% of the photoperiodic lighting in North American container tree nurseries (Landis et al. 1992). High-pressure sodium lamps have a relatively long life, are energy efficient, and have a spectral distribution that is close to optimum for both photosynthesis and photoperiod lighting. Recently, an attempt has been made to mount a centrally located lamp within an oscillating parabolic mirror (Landis et al. 1992). The lamp is kept on continuously during the dark period, but because the mirror oscillates back and forth, its light beam is intermittently cast throughout the greenhouse (Landis et al. 1992). Research suggests that one 400-W lamp used in this technology can provide photoperiodic lighting for an entire 15.2-m (50-foot) x 6.1-m (20-foot) greenhouse (R.W. Tinus, personal communication). However, there are no published data regarding the effects of the oscillating light system on conifer growth.

The objective of this study was to compare the growth and development of 7 conifer species under the standard system used at the Coeur d'Alene Nursery (intermittent lighting from incandescent bulbs) and under the oscillating light system (high-pressure sodium lamp).

Materials and Methods

Seven species were selected:

- Douglas-fir-*Pseudotsuga menziesii var. glauca* (Beissn.) Franco-seedlot elevation 1,950 m (6,400 feet)
- lodgepole pine- *Pinus contorta* var. *latifolia* Engelm. ex Loud.-1,981 m (6,500 feet)
- western redcedar- *Thuja plicata* Donn ex D.Don-1,219 m (4,000 feet)
- western larch- *Larix occidentalis* Nutt.-1,707 m (5,600 feet)
- ponderosa pine-*Pinus ponderosa Dougl. ex Laws. var. ponderosa*- 1,219 m (4,000 feet)
- western white pine- *Pinus monticola* Dougl. ex. D.Don-1,003 m (3,300 feet)
- Engelmann spruce- *Picea engelmannii* Parry ex Engelm..-2,154 m (7,000 feet)

These seedlots represented seeds collected from 4 national forests (Helena, Idaho Panhandle, Nez Perce, and Beaverhead National Forests) throughout Idaho and Montana. Seeds were sown in Styroblock (#315b) polystyrene containers----cell depth = 15 cm (6.0 inches), cell volume = 15.6 cm^3 (5.5 cubic inches), density = 764 cell s/m^2 (71 cells per square feet and 160 cells per tray)-on February 10, 1992, using a 1:1 (v/v) peat-vermiculite mixture as the growing medium. Seedlings were grown at Coeur d'Alene Nursery, Idaho (47° 37' N, 116° 49' W) using operational fertilizer and irrigation regimes.

Samples from each seedlot were grown in two greenhouses that were similar in temperature (based on readings from thermographs) and similar in the rates and timing of irrigation and fertilization but distinctly different in light source, intensity of light, and duration of light during the dark period (table 1). Lighting for photoperiod extension began on February 21, after about 85% of the seeds had germinated. Dark period lighting was activated by a photocell timer. Supplemental lighting was provided through May 18.

In one greenhouse-dimensions of 30.4 m (100 feet) x 9.1 m (30 feet)-the standard incandescent light system (hereafter referred to as the *standard treatment)* was used. The 300-W incandescent bulbs were mounted approximately 1.7 m (5.5 feet) above seedling trays and were spaced every 1.2 m (4 feet).

A single 400-W high-pressure sodium light with oscillating mirror was used in the other greenhouse, which has the same dimensions as the previously mentioned greenhouse. The light was mounted in the center of the greenhouse, about 2.5 m (8 feet) above seedling trays. Four different light environments (referred to as the *high, mid, low,* and *minimum treatments*) were created by placing seedling trays-4 trays per species for the high, mid, and low treatments; 1

Table *1-Description of light environments for the different treatments*

Treatment	Light source*	Approximate distance from source m	ft	Light intensity (μmol m^{-2} s^{-1})	Approximate duration
Standard	Incandescent	1.7	5.5	10-23	50 s, every 5 min
High	HPS-OM	2.5	8	12-30	12 s, every 18 s
Mid	HPS-OM	8.3	27	4-5	24 s, every 26 s
Low	HPS-OM	16	51	1-1.5	23 s, every 28 s
Minimum	HPS-OM	16	51	0.15	23 s, every 28 s

*300-W incandescent light bulbs were used in the standard treatment; 400-W high-pressure sodium lamp with oscillating mirror (HPS-OM) was used for the others.

tray per species for the minimum treatment---at different locations from the light (table 1). The areas of the greenhouse without experimental trees were filled with an operational greenhouse crop (total number of seedlings in the greenhouse approximately 137,000).

The minimum treatment (with oscillating light) was created by placing 1 tray of each species behind boards (35 cm (14 inches) x 66 cm (26 inches)) at the end of the greenhouse. The boards extended 20.5 cm (8.2 inches) above the trays and almost eliminated light from the high-pressure sodium lamp (table 1) but still allowed seedlings to experience the natural photoperiod. The boards were removed on May 26. Light intensity at the different locations was measured with a Li-Cor (Lincoln, NE) quantum sensor.

Following normal operational practices, all of the larch seedlings were moved on May 27 to a shelter-house under natural photoperiod, where they remained until extraction. Similarly, the other species were moved outdoors from the greenhouse on June 17. Starting at 5 weeks from sowing and continuing every 3 weeks thereafter, height was determined for 3 of the species (Douglas-fir, lodgepole pine, and Engelmann spruce) by measuring 25 seedlings per light treatment. Budset was also monitored (n = 25 seedlings per light treatment) for these species (Douglas-fir, lodgepole pine, and Engelmann spruce) 4 times during a 2-month period starting in May. The seedlings measured for height were not the same as those measured for budset, and a random selection of seedlings was made on each measurement date.

All species were extracted on July 23-24, for morphological assessment. A total of 1,036 seedlings-4 light treatments (standard, high, mid, low) x 8 seedlings per tray x 4 trays x 7 species plus the 1 minimum treatment x 20 seedlings per tray x 1 tray x 7 species--were randomly selected. Each seedling was measured for height, stem diameter, fresh weight, root volume (by displacement of water, Burdett 1979), shoot dry weight, and root dry weight (ovendrying at 70 /C for 48 hours). Shoot to root ratios were calculated using the dry weights. Seedling water balance ratio (Grossnickle et al. 1991) was calculated as shoot dry weight/(root weight x stem diameter). The water balance ratio is an estimate of the potential for water loss (transpiring surface area) in relation to the potential for water uptake and water conductance.

Using the same trays as those used for the morphological assessment, the occurrence of primary (first-formed juvenile needles) and secondary (needles grouped in fascicles) needles was estimated in the 3 pine species by counting the number of seedlings with secondary needles on May 28 (before seedlings were moved outdoors) and July 24 (at extraction). No distinction was made between seedlings having a few or many secondary needles.

Root growth potential (RGP), the ability of a seed ling to initiate or elongate new roots in an environment favorable for root growth, was determined for lodgepole pine and Engelmann spruce. The lodgepole pine seedlings were extracted on July 24, stored at 2° C for 7 days, and then tested for RGP Engelmann spruce seedlings were handled similarly as the lodge pole pine seedlings, with the exception that they were extracted on August 4. These were different seedlings from those used for the morphological assessment, but grown in the same trays.

To perform the RGP test, the medium was gently washed from the seedling roots, any active root tips were removed, and then the seedlings were grown under greenhouse conditions (19 °C air temperature (range 10 to 28 °C)) with the seedling root systems misted (18 to 22 °C root zone temperature) aeroponically (Rietveld and Tinus 1990). The number of new roots greater than 1 cm was determined after 21 days. A total of 232 seedlings was measured-4 light treatments (standard, high, mid, low) x 6 seedlings per tray x 4 trays x 2 species plus the 1 minimum treatment x 20 seedlings per tray x 1 tray x 2 species.

A preliminary analysis of variance was conducted using treatment means in a completely randomized design having 4 replications and 4 treatments (standard, high, mid, and low). This analysis was performed assuming that the two greenhouses were similar in all respects except the light environment. Because of the possible confounding effects of greenhouse environment and the lack of true replication, we present only the means and standard deviations for each treatment.

To determine if crop uniformity differed between seedlings from the 2 greenhouses, sample variances (from the morphology data) were calculated for the standard treatment (n = 32) and for the combined data of the high, mid, and low treatments (n = 96). The variances were then compared using the Dixon and Massey (1951) F-test of population variances.

Results

On May 18 and June 8, 40 to 68% of the minimum seedlings of Douglas-fir and Engelmann spruce had set bud, with little or no budset observed in the other light treatments (data not shown). As a result, the minimum seedlings lagged behind in height growth, relative to the other treatments (figure 1). On the other hand, for lodgepole pine, there was no consis-

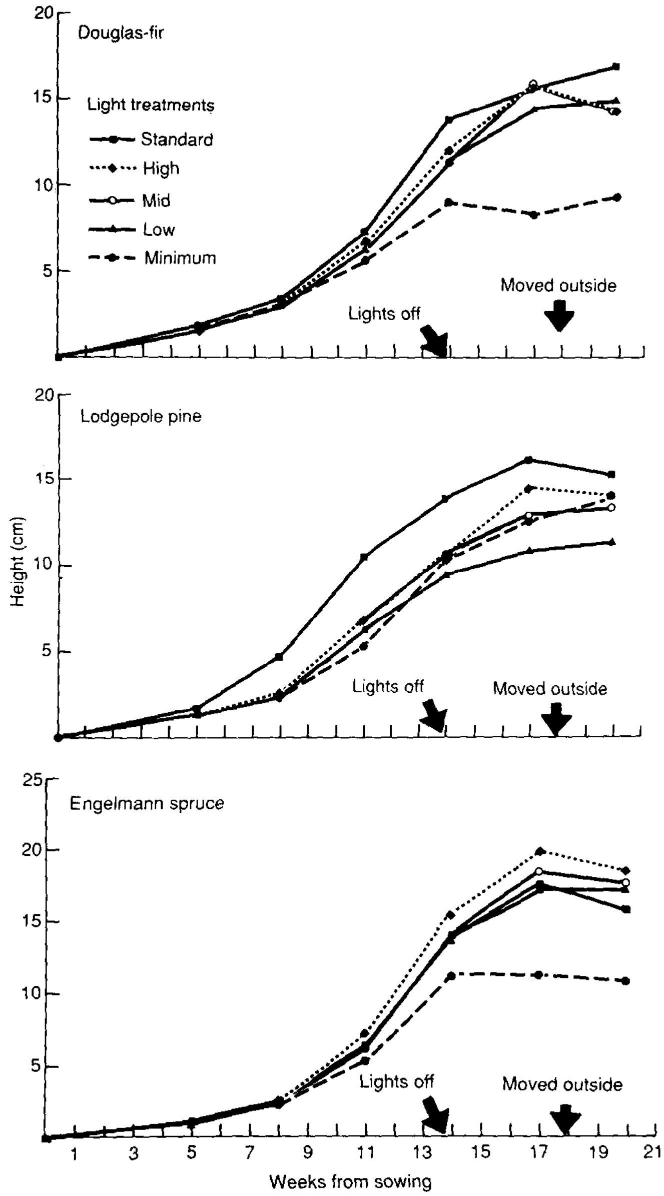

Figure 1– *Height growth of 3 species exposed to 5 different light environments (n = 25 for each mean).*

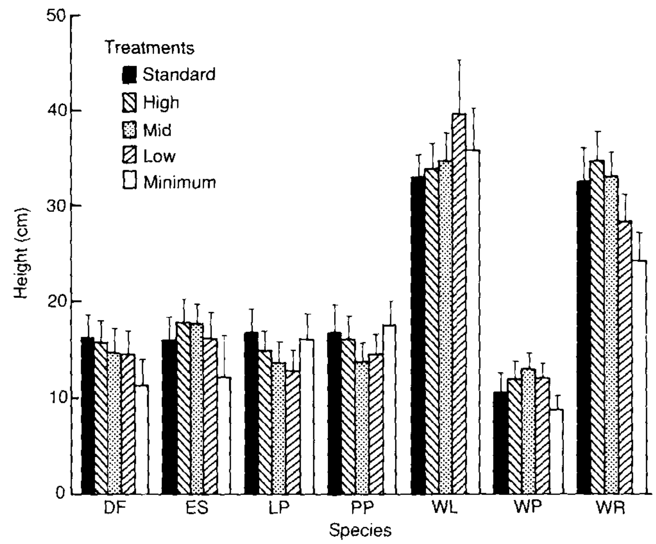

Figure 2 -*Height at the time of extraction for 5 light environments and 7 species (DF = Douglas-fir, ES = Engelmann spruce, LF = lodgepole pine, PP = ponderosa pine, WL = western larch, WP = western white pine, WR = western redcedar). Error bars represent 1 standard deviation (n = 20 for minimum; n = 32 for other treatments).*

tent budset pattern among all the light treatments, and minimum seedlings did not lag behind in growth (figure 1). In lodgepole pine, final height followed the treatment order (From tallest to shortest) of standard > minimum > high > mid > low (figure 2).

In all species except lodgepole pine, final height of seedlings grown under high light intensity (high-pressure sodium lamp) tended to be greater or very similar to the standard treatment. For Douglas-fir, lodgepole pine, ponderosa pine, and western redcedar, final height of the seedlings grown under the lowest light intensity (low treatment, high-pressure sodium lamp) tended to be less than that for seedlings under the standard treatment. For all species, there were no consistent trends for fresh weight (table 2), root volume (table 2), stem diameter (figure 3), and shoot and root weight (data not shown). Preliminary analyses of variance indicated few or no significant differences among light treatments for these five responses. On the average, the light treatments produced seedlings that met the minimum morphological standards set by the USDA Forest Service Northern Region.

Shoot to root weight ratio (table 2) was generally the smallest in the low treatment. The most notable exception was in western larch, for which the average shoot to root ratio of the low treatment was 27 to 50% greater than the other treatments. The relative rankings among treatments for water balance ratio were similar to those for shoot to root ratio (data not shown). For Engelmann spruce and lodgepole pine, the minimum light treatment resulted in the fewest

Table 2-Fresh weight, root volume, shoot to root (dry weight) ratio, and root growth potential (no. of new roots > 1 cm after 21 days) of seedli rown in different liaht environments (standard deviation in parentheses)

Species	Standard	High	Mid	Low	Minimum
Fresh weight (g)					
Douglas-fir	5.8 (1.1)	6.1 (1.2)	6.4 (1.4)	6.2 (1.1)	4.7 (1.6)
Engelmann spruce	6.5 (1.4)	7.5 (1.6)	7.0 (1.5)	7.3 (1.7)	6.0 (1.8)
lodgepole pine	10.3 (2.7)	9.6 (2.5)	10.1 (2.8)	9.6 (1.9)	7.5 (1.4)
ponderosa pine	11.7 (2.6)	12.3 (1.7)	10.7 (3.0)	11.6 (2.0)	11.2 (2.8)
western larch	10.4 (2.2)	10.9 (1-8)	10.7 (2.1)	10.0 (2.2)	10.7 (1.9)
white pine	8.2 (1.9)	7.9 (2.1)	9.2 (1.9)	8.2 (1.8)	5.8 (1.5)
western redcedar	9.6 (2.0)	9.9 (1.8)	9.0 (1.5)	8.7 (1.7)	7.7 (1.4)
Root volume (cm^3)					
Douglas-fir	4.2 (0.8)	4.7 (1.0)	5.0 (1.1)	5.1 (0.8)	3.9 (1.1)
Engelmann spruce	3.7 (1.0)	4.7 (1.0)	4.4 (0.8)	4.8 (1.0)	5.0 (1.3)
lodgepole pine	5.8 (1.7)	4.5 (1.3)	5.2 (1.4)	6.0 (1.3)	5.1 (1.0)
ponderosa pine	6.2 (1.5)	6.2 (0.9)	5.2 (1.4)	6.0 (1.1)	6.4 (1.6)
western larch	5.8 (1.4)	5.8 (1.1)	5.1 (1.5)	3.3 (1.2)	5.4 (1.4)
white pine	5.6 (1.5)	5.5 (1.5)	6.0 (1.5)	5.4 (1.5)	3.9 (1.2)
western redcedar	5.1 (1.2)	4.7 (1.1)	4.6 (1.0)	4.5 (1.0)	3.6 (0.8)
Shoot to root ratio (dry weight)					
Douglas-fir	1.3 (0.2)	1.3 (0.2)	1.2 (0.2)	1.1 (0.3)	1.1 (0.2)
Engelmann spruce	1.7 (0.3)	1.7 (0.2)	1.7 (0.2)	1.4 (0.2)	0.9 (0.2)
lodgepole pine	1.8 (0.3)	2.2 (0.5)	1.8 (0.4)	1.5 (0.3)	1.2 (0.3)
ponderosa pine	2.0 (0.4)	2.2 (0.4)	2.1 (0.4)	1.9 (0.4)	1.4 (0.3)
western larch	2.2 (0.4)	2.0 (0.4)	2.4 (0.5)	3.1 (0.6)	2.4 (0.6)
white pine	1.2 (0.3)	1.1 (0.2)	1.1 (0.2)	1.1 (0.2)	1.1 (0.4)
western redcedar	3.2 (0.4)	3.1 (0.4)	2.7 (0.3)	2.6 (0.3)	2.6 (0.4)
Root growth potential (no. > 1 cm)					
Enge4mann spruce	12.9 (15.4)	15.1 (19.2)	21.6 (23.8)	8.2 (10.7)	6.7 (10.5)
lodgepole pine	5.1 (5.3)	13.5 (11.0)	12.6 (8.9)	7.7 (7.2)	0.8 (1.7)

number of new roots, but there was considerable variation in RGP among light treatments.

When data were combined for the light treatments under the high-pressure sodium lamp and compared to the variance between seedlings in the standard treatment, there was little evidence to suggest that crop uniformity differed between the two greenhouses (table 3). In 5 of the 7 species, height variation tended to be greater from seedlings grown under the high-pressure sodium lamp, but the variances differed significantly ($P < .05$) in only western larch. In this case, seedlings grown under the high-pressure sodium lamp had a sample variance that was about 4 times greater than the height variance of seedlings grown conventionally. In general, seedling variation was not significantly different between the two greenhouses for nearly all morphological responses and species.

The light treatments appeared to have the least effect on morphological response of western white pine. This response included the needle development (primary versus secondary), where light treatment had no effect on whether primary or secondary needles were produced. In contrast, for lodgepole pine and ponderosa pine, the occurrence of primary or secondary needles was related to light treatment. For example, we estimated that close to 100% of all

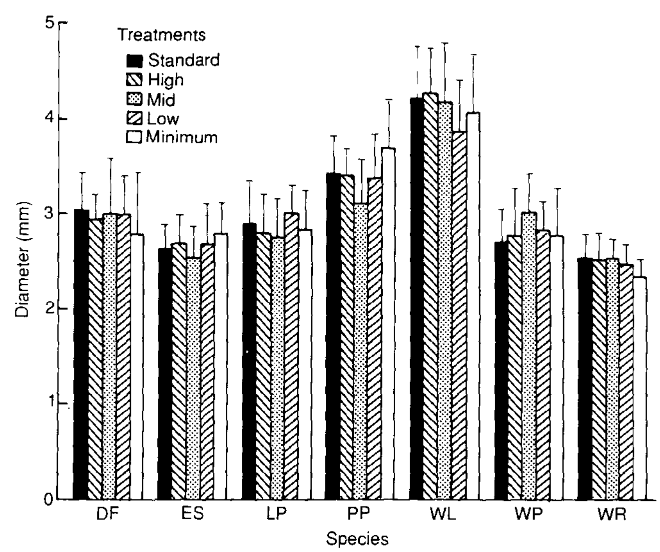

Figure 3-Diameter at the time of extraction for 5 light environments and 7 species (DF= Douglas-fir ES = Engelmann spruce, LP = lodgepole pine, PP = ponderosa pine, WL = western larch, WP = western white pine, WR = western redcedar). Error bars represent 1 standard deviation (n = 20 for minimum; n = 32 for other treatments).

Table 3-Sample variances of seedling morphology at extraction, for seedlings grown under two light sources (n = 96 for highpressure sodium lamp; n = 32 for incandescent bulbs), and F-statistic to test the hypothesis that the sample variances do not differ

Species	Sodium lamp	Incandescent bulbs	F value
Height (cm)			
Douglas-fir	6.15	5.41	1.137
Engelmann spruce	6.30	5.39	1.169
lodgepole pine	5.35	5.96	0.898
ponderosa pine	5.53	5.26	1.051
western larch	21.95	5.26	4.173*
white pine	3.04	3.46	0.879
western redcedar	15.07	10.66	1.414
Diameter (mm)			
Douglas-fir	0.21	0.16	1.312
Engelmann spruce	0.12	0.12	1.000
lodgepole pine	0.14	0.20	0.700
ponderosa pine	0.19	0.17	1.118
western larch	0.33	0.30	1.100
white pine	0.18	0.12	1.500
western redcedar	0.06	0.07	0.857
Fresh weight (g)			
Douglas-fir	1.57	1.26	1.246
Engelmann spruce	2.59	2.04	1.270
lodgepole pine	5.91	7.17	0.824
ponderosa pine	5.64	6.93	0.814
western larch	4.38	4.81	0.911
white pine	4.02	3.81	1.055
western redcedar	3.00	3.92	0.765
Root volume (cm^3)			
Douglas-fir	1.00	0.69	1.449
Engelmann spruce	0.95	1.01	0.941
lodgepole pine	2.15	2.87	0.749
ponderosa pine	1.50	2.43	0.617
western larch	2.74	1.99	1.377
white pine	2.27	2.27	1,000
western redcedar	1.07	1.55	0.690

*Variances that are significantly different (a = 0.05).

seedlings had secondary needles for all light treatments, except the minimum treatment, soon after the lights were turned off and at extraction. On the other hand, most of the minimum treatment seedlings had few secondary needles (1.3% for lodgepole, 11.2% for ponderosa) when the lights were shut down. At the time of extraction, after all seedlings had been moved outdoors, the percent of seedlings with secondary needles in the minimum treatment had risen for both species (70% for lodgepole and 28% for ponderosa pine).

Discussion

Light sources and varying light intensity for photoperiod extension affected the conifer species differently. In general, however, seedlings achieved the necessary morphological standards at the time of extraction, irrespective of treatment. That is, the seedlings met the minimum size standards as specified by Forest Service regional guidelines. In addition, with only a few exceptions (e.g., western larch), crop uniformity was not significantly altered relative to the standard lighting regime. As a result, a single highpressure sodium lamp with an oscillating mirror attachment shows much promise for providing supplemental light in a single greenhouse at Coeur d'Alene Nursery.

The height of western larch seedlings was about 4 times more variable under the oscillating mirror system than under the standard greenhouse regime. This occurred because the low treatment resulted in seedling height that was about 14 to 16% greater than the average height of seedlings in the high and mid treatments. In addition, the coefficient of variation for height in the low treatment (14%) was about 1.6 to 2 times greater than that found for the high, mid, and standard treatments. It appeared that low seedlings allocated resources toward height growth, as evidenced by relatively small root volumes and large shoot to root or water balance ratios. However, if the allocation pattern was related to a shade-induced height increase (Landis et al. 1992), we would have expected the minimum seedlings to also be relatively taller. The latter result did not occur. Dance and Running (1985) suggested that height growth, in response to light or moisture regimes, was not very predictable in young western larch seedlings. Similar to our study, they found considerable variation in height in western larch. In contrast, however, the low light treatments (27 or 37% full sunlight) used in their study tended to produce seedlings that were shorter than those grown under higher light (70% full sunlight).

Needle development (primary versus secondary) in lodgepole pine and ponderosa pine seedlings (but not western white pine) was apparently influenced by supplemental light. By providing light during the crop cycle, needle development can be influenced in some pine species. However, the relationship between needle type and subsequent field performance is largely unknown. Container nurseries in British Columbia favor the development of secondary needles for improved field performance (van Steenis 1993). In contrast, recent research at Coeur d'Alene Nursery and the University of Idaho (Omi et al. 1993) showed that lodgepole pine seedlings with primary needles were more cold-hardy, had greater water-use efficiency (ratio of photosynthesis to transpiration), and had significantly greater growth than secondary needle type seedlings in greenhouse, common garden, and outplanting experiments (unpublished data). The poor performance of the secondary needle type seedlings, however, may have been due to the application of a late-season (August) photoperiod extension. Detrimental effects of daylength extension late in the crop cycle have been noted in other species (Arnott and Mitchell 1982, Grossnickle et al. 1991, Grossnickle and Arnott 1992, Lavender and Stafford 1985, Laven der 1989, Silim et al. 1989).

We were pleased with the performance of the high-pressure sodium lamp with oscillating mirror because seedlings grew to meet our regional stock standards for morphology. Furthermore, we estimated that relative to the oscillating light, the standard incandescent technology has a 1.5-fold and 7-fold increase in initial installation costs and electricity use, respectively (table 4). Using the assumption stated in table 4, we calculated a savings of about $1,130.00 (per greenhouse) related to bulb and installation costs. Over the course of a year, assuming two crops (one sown in January and the other sown in February) requiring supplemental lighting for 90 to 120 days, the savings in electricity using the oscillating mirror is approximately $350.00 per greenhouse. These estimates exclude the savings in bulb replacement due to the extended bulb life of the high pressure sodium light (table 4).

Table 4 -*Cost comparisons of a greenhouse with incandescent bulbs and a greenhouse with a single high-pressure sodium lamp and oscillating mirror*

	Incandescent bulbs	High-pressure sodium lamp
No. of bulbs/greenhouse	90	1
Bulb life (hours)	1,000	25,000
kW hourslnight/greenhouse*	32.4	4.8
Costs		
Bulbs/greenhouse	$630‡	$50
Fixtures + installation	$1,550§	$1,000¶
ElectricitylnightJgreenhouse†	1.94	0.29

*Kilowatt hours per night = number of bulbs x kilowatts per bulb x hours light are on.
† Cost of electricity per night per greenhouse = kilowatt hours x $0.06 per kilowatt hour.
‡ 90 bulbs x $700 per bulb.
§ Light fixtures ($750.00) + materials and labor ($800.00) =$1,550.00.
¶ Light fixtures ($500.00) + materials and labor ($500.00) = $1,000.00.

Managers need to recognize, however, that a bulb failure in the oscillating light regime would create a dark period in the entire greenhouse. In our standard lighting regime, where 90 incandescent bulbs light the greenhouse, a single bulb failure probably has minimal effects. Because a single night without supplemental light can have significant height growth effects (Arnott 1985), routine maintenance and an alarm system are recommended for use of the high-pressure sodium lamp with oscillating mirror. We also recommend that the system be tested for varying combinations of nursery location, sowing date, seedlot elevation, and species.

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Stock Quality Assessment: Forecasting Survival or Performance on a Reforestation Site

Steven C. Grossnickle and Raymund S. Folk

Research scientists, Forest Biotechnology Centre B.C. Research Inc., Vancouver, British Columbia

Seedlings are exposed to a wide range of environmental conditions on reforestation sites. These conditions could result in stress that reduces survival and/or growth of newly planted seedlings. Field survival and field performance potential need to be distinct areas of evaluation when selecting and interpreting stock quality tests. Tests that measure the functional integrity of seedlings help forecast their survival capability. Tests that simulate anticipated field environmental conditions help forecast a seedling's physiological performance and potential for growth on a reforestation site. Tree Planters' Notes 44(3): 113-121; 1993.

Stock quality assessment has evolved to include both morphological and physiological tests (see reviews by Sutton 1979, Chavasse 1980, Jaramillo 1980, Schmidt-Vogt 1981, Ritchie 1984, Duryea 1985a, Glerum 1988, Lavender 1988, Puttonen 1989, Hawkins and Binder 1990, Johnson and Cline 1991, Omi 1991). The wide array of testing procedures has sometimes led to confusion in selection of tests for specific purposes. Part of this confusion stems from the fact that stock quality tests can have one of two different purposes: evaluating nursery development (for example, determining nursery growth phase or evaluating readiness for lifting and storage) or forecasting field survival and/or growth (Duryea 1985b). A clearer understanding of the nature and purpose of specific testing techniques will help nursery personnel and regeneration silviculturists choose appropriate tests and make more effective decisions.

With any type of stock quality assessment procedure, differences in test results could be due to species, genetic variability of seedlots, variations in nursery culture, cold or frozen storage regimes, and variations in testing conditions. Separate testing standards need to be developed for seedlings produced from various combinations of the above nursery decisions. Seedling users also need to be aware that the mishandling of stock during transport to planting sites, improper planting procedures, and unpredictability of field site environmental conditions will influence how test results agree with initial seedling survival and/or growth on a reforestation site.

Stock quality assessment as it relates to forecasting either initial field survival or field performance potential (i.e., potential for initial growth on a reforestation site) is the focus of this paper. Testing procedures are discussed and evaluated for their suitability to provide information on these aspects of stock quality assessment. Understanding the benefits and limitations of these testing approaches will provide nursery personnel and regeneration silviculturists with a better appreciation of their potential utility within an operational forest regeneration program.

Planting Stress and Stock Quality Assessment

Seedlings can be exposed to stress just after they are planted on a reforestation site. This is usually attributable to water stress because root confinement, poor contact of roots with soil, and low root system permeability can limit water uptake from the soil needed to meet transpirational demands placed upon seedling shoot systems by atmospheric conditions (Kozlowski and Davies 1975, Burdett 1990). Planting stress will be overcome only if seedlings have functional physiological processes required for morphological development, primarily root growth, to occur. When root growth occurs in newly planted seedlings, water stress is reduced and a seedling's physiological processes then have the capability to respond in a normal manner (Sands 1984, Grossnickle 1988, Carlson and Miller 1990, Brissette and Chambers 1992).

Further limitations on the physiological processes of newly planted seedlings can occur from exposure to environmental extremes on a reforestation site. The most dramatic of these are alterations in heat exchange processes and site-water relations (Miller 1983). Low temperature and drought conditions are two predominant types of environmental stress occurring on reforestation sites.

First, freezing events can cause frost damage (Nilsson and Eriksson 1986, Grossnickle et al. 1991b) and/or reduced gas exchange capability (Neilson and Jarvis 1976, DeLucia 1987, Grossnickle and Arnott 1992) in newly planted seedlings. Low soil temperature conditions in early spring can cause reduced root growth (Nambiar et al. 1979, Lopushinsky and Kaufmann 1984, Grossnickle et al. 1991b), and/or restrict water uptake, resulting in water stress (Kaufmann 1977, Nambiar et al. 1979, Lopushinsky and Kaufmann 1984, Grossnickle 1988).

Second, newly planted seedlings can be exposed to drought through limited soil moisture and/or high evaporative demand conditions of the atmosphere. Drought conditions cause seedling water stress by restricting water uptake from the soil (Kaufmann 1979, Dixon et al. 1983, Grossnickle and Reid 1984, Sands 1984, Livingston and Black 1987a, Brissette and Chambers 1992) and by inadequate stomatal control as evaporative demand increases (Grossnickle and Blake 1987, Livingston and Black 1987b, Grossnickle and Arnott 1992). The result of increased water stress in newly planted seedlings is a reduction in growth (Nambiar and Zed 1980, Margolis and Waring 1986, Livingston and Black 1988, Grossnickle and Heikurinen 1989). As a result, planting stress can be exacerbated by field site environmental conditions that reduce growth and delay a seedling's capability to occupy the site.

No stock quality assessment program can alleviate the stress seedlings are exposed to on reforestation sites. However, a program that defines a seedling's functional integrity could determine whether it has the capability to survive potentially stressful environmental conditions, because initial field survival is dependent on whether a seedling has the physiological capability to function normally at time of planting. On the other hand, a program that defines field performance potential by measuring a seedling's physiological responses and morphological development under simulated environmental conditions of the Planting site would provide information on field growth potential. Though testing for field performance potential would provide information on survival capability, there is no guarantee that testing for survival would provide sufficient information on field performance potential. Thus, stock quality assessment as it relates to a seedling's initial field survival or field performance potential are considered distinct areas of evaluation and are examined as separate topics.

Field Survival Capability

Currently, there are a number of testing procedures that provide information on the initial survival potential of operationally produced stock. These tests measure a seedling's vitality under a specific set of conditions that defines a certain level of quality when tested (Ritchie and Tanaka 1990, Langerud 1991). These kinds of tests measure the functional integrity of seedlings, which helps determine their initial survival capability. Functional integrity indicates whether a seedling is, or is not, damaged to the point of limiting primary physiological processes. The intent of these testing approaches is to remove seedlings that do not meet certain minimum physiological performance standards (i.e., the "bad apple concept"). Seedlings that meet minimum standards probably have a greater capability to survive in all but the most severe of field site environmental conditions (Sutton 1988).

The following are examples of testing procedures that provide information on the functional integrity of tested seedlings. These tests have been developed for the purpose of batch-culling poorly grown and handled seedlings. They are used to categorize large groups of seedlings, all having a similar nursery culture regime or from a similar seed source, by measuring a subsample from the entire population. A brief description of each test is given below. Further specific information on each testing procedure can be found in the cited articles.

1. **Root growth capacity** is a measure of a seedling's ability to regenerate new roots and an indirect measure of a seedling's overall physiological condition (Stone 1955, Ritchie and Dunlap 1980, Rit chie 1985, Burdett 1987, Ritchie and Tanaka 1990, Sutton 1990).
2. **Oregon State University vigor test** is a measure of a seedling's subsequent survival after exposure to a single controlled stress event (15 minutes at 30 °C and 30% relative humidity) (McCreary and Duryea 1985, 1987; Lavender 1988).
3. **Shoot water potential** of potted seedlings after a set time period is an indirect measure of a root system's capability to absorb water and thus maintain a proper seedling water balance (McCreary and Duryea 1987).
4. **Needle conductance** (Orlander and Rosvall-Ahne brink 1987) and **transpiration** (Langerud et al. 1991) are measures of the water movement capability of needles and an indirect measure of a root system's capability to absorb water and the xylem's capacity to transport water to the needles.
5. **Infrared thermography** is a measure of foliage heat exchange (i.e., temperature) resulting from transpiration and an indirect measure of a root system's capability to absorb water and the xylem's capability to transport water to the needles (Weatherspoon and Laacke 1985, Orlander et al. 1989).

6. **Root system water loss capability** measured under positive pressure is an indirect measure of root system integrity (Ritchie 1990).
7 **Fine root electrolyte leakage** is an indirect measure of root system integrity (McKay and Mason 1991, McKay 1992).
8. **Variable chlorophyll fluorescence** is a measure of photosynthesis and an indirect measure of a seedling's overall physiological condition (Vidivar et al. 1989, 1991).
9. **Stress-induced volatile emissions** is a measure of cell injury due to membrane breakdown (Hawkins and DeYoe 1992).

The above tests measure different morphological or physiological parameters in relation to initial field survival of tested seedlings. Seedlings that do not meet certain minimum performance standards usually have poor field survival capability. On the other hand, seedlings that meet certain minimum performance standards have a greater capability to survive under typical reforestation site conditions.

However, no single testing procedure accurately forecasts field survival under all circumstances. For example, an extensive operational test of root growth capacity (RGC) found that RGC had a poor relationship with field survival under some circumstances (Binder et al. 1988). Seedlings with poor RGC had a higher probability of increased mortality. However, they found that even seedlings with high RGC could still have an unacceptable mortality level after field planting. This example emphasizes the limitations inherent in using a single test as an indicator of a seedling's overall quality. Seedlings have a wide array of physiological processes that continually respond to environmental conditions. Proper stock quality assessment must consider the dynamic and interdependent nature of a seedling's physiological processes.

Field Performance Potential

A seedling's performance on a reforestation site depends on its inherent growth potential and the degree to which the environmental conditions of the field site allow this growth potential to be expressed. Thus, the degree to which a seedling can adapt to site conditions just after planting influences its initial growth on the reforestation site (Burdett 1983). To determine a seedling's field performance potential, the seedling should be assessed in relation to anticipated environmental conditions at the site (Duryea 1985b; Sutton 1982, 1988; Puttonen 1989; Grossnickle et al. 1988, 1991a; Hawkins and Binder 1990). In addition, an array of morphological and physiological tests that examine factors important for determining a seed ling's field performance potential is required because stock quality reflects the expression of a multitude of physiological and morphological attributes (Ritchie 1984). An array of tests that simulate anticipated field environmental conditions would help forecast seed lings physiological performance and potential for growth on a reforestation site.

To measure a seedling's physiological response and growth under a range of environmental conditions, tests should define performance under optimum environmental conditions, as well as define stress tolerance and avoidance parameters (Levitt 1980). This approach was first presented by Timmis (1980), who developed a series of tests to simulate essential physiological responses and growth behavior of seedlings in any environment and derived numerical values for these responses. Examples of possible material and performance attribute tests important in defining a seedling's field performance potential are shown in table 1. In tests measuring performance attributes, whole seedlings are subjected to some test condition that integrates their response over time or to a range of environmental conditions (Ritchie 1984). In tests measuring material attributes, an individual morphological or physiological parameter of the seedling is tested (Ritchie 1984).

Seedlings are normally exposed to some type of stress after planting on a reforestation site. Anticipated environmental conditions could be defined by reforestation silviculturists during on-site development of regeneration prescriptions. Test environments could then be selected that match this range and combination of anticipated environmental conditions.

Effective determination of field performance potential depends on the selection of a smaller number of morphological and physiological attributes from a master table (table 1). As described earlier, low temperature and drought are two predominant types of environmental stress that could occur on reforestation sites. Possible attributes to consider measuring on seedlings to be planted on potentially cold or droughty reforestation sites are described in figures 1 and 2, respectively. This approach to stock quality assessment is designed to allow the user to have information from a number of material and performance attribute tests that are important for their intended purpose.

Results from testing programs could be integrated to develop a means of expressing the overall physiological and morphological quality of seedlings. The performance potential index (PPI) has been developed to integrate material and performance attribute tests for a comprehensive perspective of seedling field per-

Table 1 -*Possible material (morphological and physiological) and performance attribute tests and their intended purposes for defining field performance potential*

Morphological attribute tests

Height: General measure of photosynthetic capacity and transpirational area (Armson and Sadreka 1979); greater height is an advantage on sites where brush competition and animal browsing are potential problems (Cleary et al. 1978).

Diameter: General measure of a seedling's durability, root system size, and protection from drought and heat damage; provides support to withstand physical abuse (Cleary et al. 1978).

Needle surface area: Direct measure of potential photosynthetic or transpirational surface area.

Root surface area or dry weight: Good indicator of absorptive root surface (Thompson 1985).

Needle primordia: Important indicator of shoot growth potential (Colombo 1986).

Seedling water balance ratio (needle dry weight/[stem diameter x root dry weight]): Measure of drought avoidance potential for situations where water absorption lags behind transpiration (Grossnickle et al. 1991 a).

Physical attribute tests

Osmotic potential at turgor loss point: Quantitative measure of drought tolerance (Tyree and Jarvis 1982).

Maximum bulk modulus of elasticity: Quantitative measure of cells' elasticity, with greater elasticity representing greater turgor maintenace (Tyree and Jarvis 1982).

Seedling water movement: Measurement of water movement capability in relation to a plant's resistances along the pathway (i.e., root xylem, needle) to the atmosphere (Hinckley et al. 1978); provides measure of drought avoidance potential.

Cuticular transpiration: Measure of needle's capability to avoid water loss after stomata have theoretically closed (Vanhinsberg and Colombo 1990).

Days to terminal budbreak: Direct measure of bud dormancy status (Lavender 1991) and indirect measure of changes in drought and cold temperature tolerance (Burr 1990).

Performance attribute tests

Root growth capacity: General indicator that all systems in a seedling are functioning properly (Ritchie 1984) and measure of seedling performance potential (Burdett 1987).

Root growth capacity at low root temperature or after exposure to drought conditions: Measure of a seedling's performance and root growth capability under stressful soil conditions (Grossnickle et al. 1991 a).

Frost hardiness: Measure of a seedling's tolerance to freezing temperatures (Glerum 1985).

Net photosynthesis 14-day integral under optimal environmental conditions: Direct measure of a seedling's photosynthetic capability (Grossnickle et al. 1991 a).

Net photosynthesis 14-day integral at low root temperatures: Direct measure of seedling tolerance to low temperatures (Grossnickle et al. 1991 a).

Net photosynthetic capability at decreasing predawn water potentials: Direct measure of a seedling's tolerance to drought (Grossnickle et al. 1991 a).

Gas exchange capability at various vapor pressure deficits: Measure of stomatal conductance, transpiration, and/or net photosynthesis used to define the efficiency of a plant's CO_2 uptake in relation to water loss (Landsberg 1986).

formance potential (Grossnickle et al. 1991c). The PPI provides a means for collectively interpreting the results from a group of tests within a standardized, yet quantitative framework. The PPI, measured immediately before planting, has been used to clarify the relationship between nursery culture regimes (Grossnickle et al. 1991a-c) or stock types (Grossnickle and Major 1993a,b) with field performance. Another approach to integrating test results has been proposed by D'Aoust et al. (1991). Their approach characterizes seedling performance potential with ten morphological and physiological parameters. Principal component analysis was used to identify a smaller set of parameters that adequately represent information contained in the whole set. Measurement of four variables (i.e., diameter, stem height, shoot water potential at planting, and root growth capacity) before field planting were sufficient to characterize the morphology and physiology of the seedlings produced.

However, limitations are inherent in stock quality assessment depending on when the test is used and what morphological and physiological attributes of the seedlings are measured (Puttonen 1989). These limitations influence the usage of test results. Because these tests are conducted just prior to planting, their ability to forecast seedling growth on a reforestation site has a limited time frame. Consequently, a number of studies have reported various levels of success in forecast ing growth on a reforestation site (Grossnickle et al. 1991a-c; Grossnickle and Major 1993 a,b; Major et al. 1993; Folk et al. 1993).

Inconsistencies in forecasting seedling growth in the field are due to several factors. First, errors in describing potential seedling performance can occur in a system that aggregates many plant physiological and morphological characteristics (e.g., cells, tissues, and organs) having different turnover times (Gardner et al. 1982). Seedlings have a dynamic pattern to their seasonal physiological response and morphological devel-

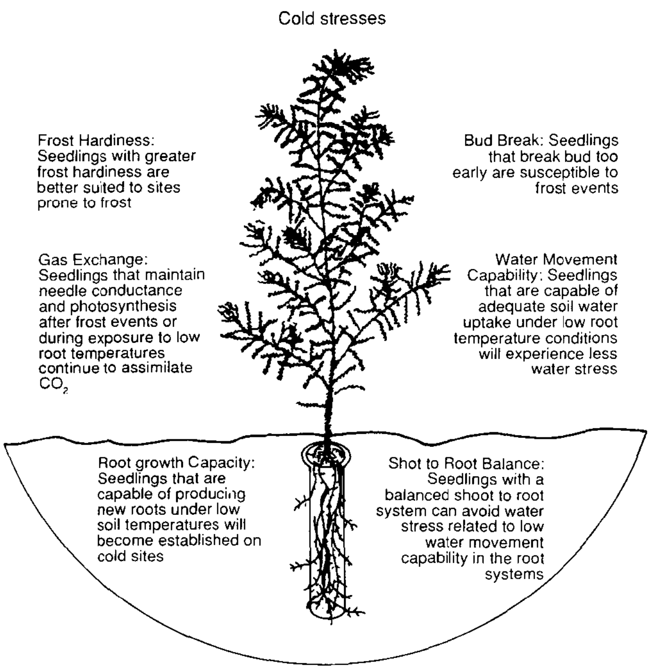

Figure 1 *-Possible testing procedures for determining seedling field performance potential in response to cold reforestation site environmental conditions.*

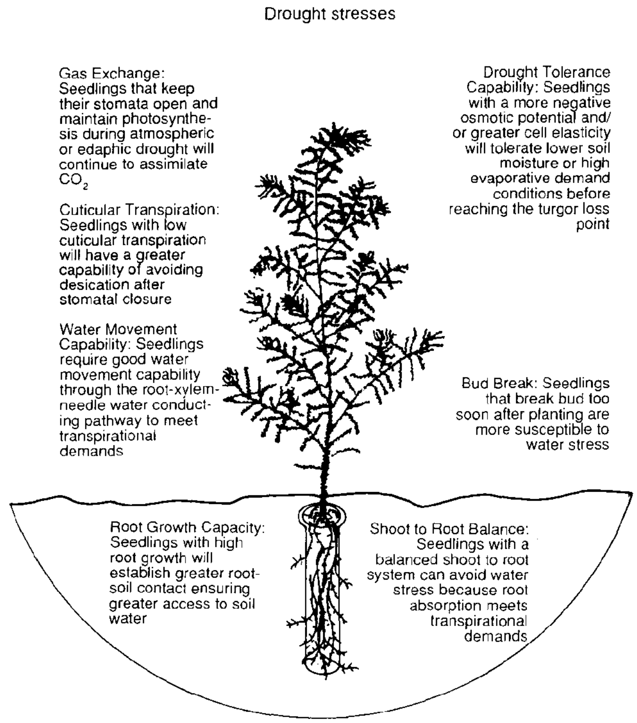

Figure 2 *-Possible testing procedures for determining seedling field performance potential in response to drought reforestation site environmental conditions.*

opment (Fuchigami et al. 1982, Burr 1990, Ritchie and Tanaka 1990). Any testing procedure is just a "snapshot" of a single point in time along this seasonal pattern, making it difficult to accurately forecast all future seasonal patterns. Second, seedling field site performance may not always match stock quality test results because it is difficult to simulate all possible combinations of environmental stress-that is, duration, timing, intensity, frequency-that could occur under actual field site conditions. This makes it difficult to always define the proper level of environmental stress needed to obtain useful information on field performance potential that would forecast growth of seedlings on reforestation sites.

This does not mean that forecasting seedling field performance potential is not possible. One could come closer to defining a seedling's actual field response by using a greater number of material and performance attribute tests designed to give information on a seedling's overall response to potentially limiting site related environmental conditions. Also, information on typical seasonal trends of environmental conditions, for reforestation sites within defined ecosystems, could be used to develop test environments that provide a fair representation of what seedlings might be exposed to in the field. With this information, attributes such as those in table 1 could be selected to characterize a seedling's response to expected environmental conditions of a specific planting site.

In the following example, we describe how actual field response was forecasted by using a combination of material and performance attribute tests. Field performance potential was measured, under controlled laboratory conditions, on western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) seedlings destined for late winter planting when exposure to low temperature conditions was probable (Grossnickle et al. 1991a). Western hemlock seedlings treated with short-day (compared to long-day) dormancy induction treatments had better field performance potential in the following tests (table 1, figure 1):

1. Water movement capability through the plant atmosphere continuum at 5 °C root temperature.
2. Net photosynthesis 14-day integral with root temperature at 5 °C.
3. Root growth capacity at a root temperature of 5 °C.

4. Frost hardiness of the whole shoot system to -18 /C.
5. Seedling water balance ratio.

One month after planting on a reforestation site, and after exposure to low temperatures and frosts in late winter and early spring, short-day treated seedlings had the least needle damage due to frosts and the greatest amount of new root growth (Grossnickle et al. 1991b). In addition, short-day treated seedlings had greater needle conductance and net photosynthesis after frost events during this late winter and early spring period (Grossnickle and Arnott 1992). In this example, material and performance attribute tests were selected in anticipation of low-temperature site conditions just after planting. This group of tests yielded a fairly accurate forecast of subsequent field performance.

Attributes defined in table 1 are not an all-inclusive list, but an example of parameters to consider for a comprehensive stock quality assessment program. Inclusion of alternative material or performance attribute tests in the master table is possible depending upon the user's needs and further development of testing procedures. A number of authors have identified additional seedling physiological and morphological characteristics that might be important for inclusion in a master table (Timmis 1980, table 1; Burdett 1983, table 1; Puttonen 1989, table 2). Material and performance attribute tests need to be developed with these physiological and morphological characteristics in mind.

Conclusions

Stock quality testing procedures that measure the functional integrity of seedlings at time of planting help to forecast initial survival capability. A number of testing approaches are available that determine whether stock meets certain minimum physiological standards, thus allowing for removal of seedlings with poor field survival capability.

On the other hand, testing for field performance potential requires a separate approach to forecast seedlings physiological response and growth on a reforestation site. A combination of material and performance attributes tests, designed to provide information on a seedling's physiological response and growth to potentially limiting site-related environmental conditions, comes closer to defining actual field performance. Whether this approach is practical in all operational reforestation programs is questionable.

The sophisticated equipment and technical expertise required to conduct field performance potential testing, as has been described, will limit its use. One can speculate that field performance potential testing could be beneficial to nursery personnel in developing new stock types or nursery cultural regimes. Regeneration silviculturists could use field performance potential testing when planting seedlings on field sites where survival and/or growth is known to be limited. Field performance potential testing has been used in our lab to test seedlings from a number of operational reforestation programs where field site conditions or stock type performance was considered limiting to reforestation success.

Stock quality testing using the above described approaches would provide a means for nursery personnel and regeneration silviculturists to better forecast initial field survival capability or field performance potential of seedlings. With this information, forest regeneration programs can work towards producing seedlings that meet the definition of stock quality-"fitness for purpose."

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Tree Planter's Notes, Volume 44, No. 3 (1993)

Sowing at 1.5-cm (0.6-inch) Depth Produces Heaviest Douglas-Fir Roots in Small Containers

Don Minore, Howard G. Weatherly, and Patrick G. Cunningham

Plant ecologist, forestry technician, and statistician, USDA Forest Service Pacific Northwest Research Station Forestry Science Laboratory, Corvallis, Oregon

Sowing seeds of Douglas-fir (Pseudotsuga menziesii *(Mirb.) Franco) at five depths in Leach Super Cells® indicated that the only benefit of deep sowing in small containers occurred at a depth of 1.5 cm (0.6 inch). Planting at this depth produced heavier roots without a significance reduction in seedling emergence.* Tree Planters' Notes 44(3): 122-124; 1993.

The sowing depth recommended for Douglas-fir *(Pseudotsuga menziesii* (Mirb.) Franco) in cultivated nursery soil is 0.3 to 1.0 cm (0.1 to 0.4 inch) (Owston and Stein 1974). Although sowing depths may vary, Steven (1928) found that Douglas-fir germination was not seriously reduced in a sandy loam until sowing depths exceeded 1.9 cm (0.7 inch). Show (1930) noted that germination rates, germination percentage, and the total number of Douglas-fir seedlings produced decreased, but that the percentage of large, high-quality seedlings tended to increase with sowing depth.

Minore (1985) also found that fewer but larger Douglas-fir seedlings were produced at greater sowing depths. A sowing depth of 1 cm (0.4 inch) produced the best height growth in a greenhouse soil without reducing emergence, but total seedling weigths increased with sowing depths of 0.5 to 4.5 cm (0.2 to 1.8 inch) when Minore sowed seeds in large pots (15 cm [6 inches] diameter and 15 cm [6 inches] deep) filled with a peat-vermiculite mixture. He concluded that a sowing depth of 2.5 cm (1.0 inch) in the peat-vermiculite mix used in the production of container stock would require 40% more seed and 2 weeks more emergence time than the normal sowing of 0.3 to 1.0 cm (0.1 to 0.4 inch) but should produce 50% heavier seedlings after 6 months of growth.

These conclusions on sowing depth in large pots may not apply to the smaller containers usually used in producing container planting stock. Acceptable seedlings can be produced in many types of containers, however, and no single container type is best for all nurseries and outplanting sites (Landis et al. 1990). We sowed Douglas-fir seeds at several depths in Leach Super Cells, which are the most popular container type for tree improvement and other uses where consolidation is critical. Our objective was to determine the effects of sowing depth on seedling emergence and growth in these smaller containers.

Methods

Douglas-fir seeds collected in Oregon near the mouth of the Columbia River at an elevation of less than 152 m (500 feet) were sown at five depths in Ray Leach Super Cell® containers:

0.5 cm (0.2 inch)
1.5 cm (0.6 inch)
2.5 cm (1.0 inch)
3.5 cm (1.4 inches)
4.5 cm (1.8 inches)

Leach cells are one of a variety of container types. They produce plug seedlings that are typical of those used in the Pacific Northwest.

The containers were 21 cm (8.3 inches) tall, with an inside top diameter of 4 cm (1.6 inches). They were partially filled to five levels with a 1:1 mixture of peat and vermiculite. Seeds then were placed on the surface, and additional medium was added to achieve the five sowing depths. No surface grit was used. Every sowing depth was replicated in 19 containers with 6 seeds sown at a single depth in each to provide a replicated measure of seedling emergence. The depths were randomized in a rack that held 7 rows with up to 14 containers in each row. Ninety-five of those containers were used (5 treatments replicated 19 times), thus filling all but three spaces in the rack. That rack was placed in a greenhouse, watered daily, and given supplemental lighting as needed to provide 16-hour photoperiods. Thus, 95 experimental units (the containers) were used in a completely random design.

Seedling emergence was tallied at weekly intervals. The seedlings were thinned to the single tallest in each container when two or more developed epicotyls. All were fertilized at weekly intervals with equal amounts of a dilute nutrient solution (1.7 ml "Schultz Instant" Liquid Plant Food per liter H_20). Nine months after the seeds were sown, shoot heights were measured, and the seedlings were harvested. Shoot, root, and total seedling weights were determined after ovendrying for 48 hours at 65 /C (149 /F).

Seedling emergence percentages, shoot heights, shoot weights, root weights, and shoot to root ratios were compared among sowing-depth treatments by analyses of variance. An orthogonal polynomials analysis procedure was then used to determine the presence or absence of trends in relating these response variables to sowing depth. The 4.5-cm treatment was not included in these analyses because of the small

caught up, and total emergence at the 0.5- and 1.5-cm (0.2- and 0.6 inch) depths was similar (table 1). At depths below 1.5 cm (0.6 inch), emergence rate and total number of emerging seedlings decreased with sowing depth. Those decreases were significant ($P < 0.01$) and nonlinear.

Sowing depth did not significantly affect seedling shoot heights ($P = 0.28$), but the uppermost roots of seedlings grown from deeply sown seeds were at greater depths than those sown at 0.5 cm (0.2 inch)

Results and Discussion

After lagging slightly behind the 1.5-cm (0.6-inch) depth during the second week, seedling emergence at 0.5 cm (0.2 inch) was faster than at other depths (figure 1). Emergence at 1.5 cm (0.6 inch) eventually

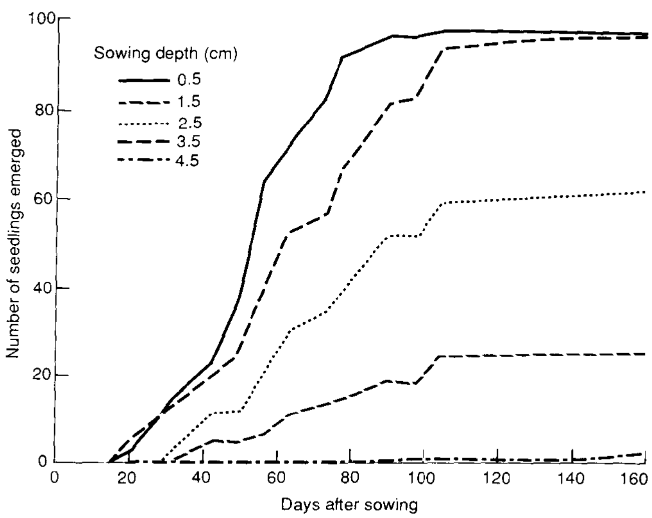

Figure 1-*Douglas-fir seedling emergence after 114 seeds per depth (6 per container) were sown at each of five depths.*

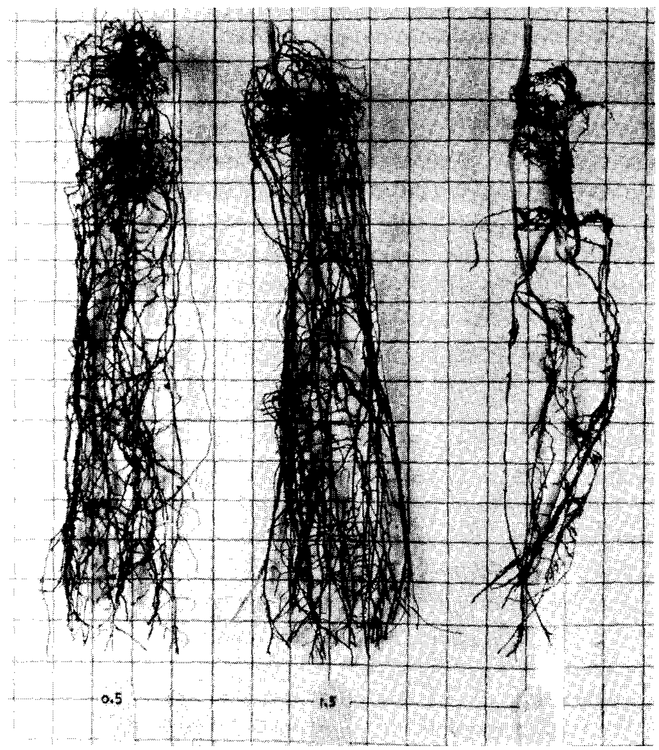

Figure 2-*Roots of the largest Douglas-fir seedlings sown at depths of 0.5* (left), *1.5, and 2.5* (right) *cm (0.2, 0.6, and 1.0 inch). Stems were cut at the surface of the planting medium and lined-up along the 0.5-inch (1.3-cm) grid to compare root distribution at each depth. Note that the origin of topmost roots became deeper as sowing depth increased.*

Table 1-*Average emergence, heights, weights, and shoot to root ratios of Douglas fir seedlings sown at five depths in Ray Leach Super Cells®*

Sowing depth	Number of cells with seedlings	Seedling emergence* (%)	Shoot height† (cm)	Shoot weight‡ (g)	Root weight‡ (g)	Shoot/root ratio
0.5 cm (0.2 in)	19	86.0 a (3.2)	8.38 a (0.38)	0.217 a (0.017)	0.368 b (0.022)	0.594 a (0.033)
1.5 cm (0.6 in)	19	85.1 a (3.8)	9.21 a (0.38)	0.266 a (0.016)	0.470 a (0.028)	0.582 a (0.025)
2.5 cm (1.0 in)	18	54.4 b (7.4)	8.14 a (0.70)	0.227 a (0.027)	0.333 b (0.017)	0.674 a (0.070)
3.5 cm (1.4 in)	16	22.0 c (3.6)	7.52 a (0.90)	0.202 a (0.032)	0.267 b (0.042)	0.884 a (0.165)
4.5 cm (1.8 in)	2	1.8	4.15	0.100	0.095	1.972

Averages in the same column followed by a different letter are significantly different ($P < 0.05$). Standard error of the mean in parentheses.

*Based on 114 seeds at each depth (6 seeds in each of 19 cells)

†Divide by 2.54 to obtain inches.

‡Multiply by 0.03527 to obtain ounces.

Rooting Baldcypress Stem Cuttings

D. L. Copes and W. K. Randall

Principal plant geneticist, USDA Forest Service, Pacific Northwest Research Station, Corvallis, Oregon area geneticist, USDA Forest Service, Siuslaw and Willamette National Forests, Corvallis, Oregon

Stem cuttings of baldcypress clones were rooted under environmental conditions normally used for Douglas-fir cuttings. Rooting of cuttings in three bed areas receiving different amounts of intermittent mist were evaluated. The 23-year-old clones rooted best (58%) in the wettest area of the rooting bed (50% moisture content). Cuttings developed large tap roots that greatly exceeded the size of the aboveground portion of the plants. Tree Planters' Notes 44(3): 125–127; 1993.

In western Oregon, the search for plants to protect shores of reservoirs from water erosion led us to propagate baldcypress (*Taxodium distichum* (L.) Rich.). Reservoirs established for flood control are subject to great fluctuations in water level: they are routinely drawn down to low water levels each fall before the start of the rainy season. The drawdown can exceed 30 vertical m (100 feet) and results in exposing the bare banks to wave erosion. Trees planted on exposed banks during low water are likely to be submerged under many feet of water for several consecutive months. Baldcypress is a species from the southern United States that thrives in wet areas and can tolerate prolonged submersion (Hall et al. 1946). The species also grows along river drainages in the northern extremes of its range in southern Illinois and southwest Indiana. Baldcypress tress planted in the northeastern United States and southern Canada withstand minimum winter temperatures of −29 to −34 °C (−20 to −29 °F) (Wilhite and Toliver 1990). Unfortunately, baldcypress in the most northern populations produce very little seed (Mattoon 1915).

In 1989 we could not locate a source of seed from cold-hardy populations of baldcypress for planting, so we decided to root stem cuttings and plant the rooted cuttings instead of seedlings. In this report, we describe the rooting environment, our rooting results, and the somewhat unusual rooting characteristics of baldcypress.

Materials and Methods

Cuttings were made from branch tips of 3-year-old rooted ramets of 20-year-old trees (ortets) that had been established from rooted branch tips collected from 10 trees growing near Corvallis, Oregon. These 10 parent trees grew from seed gathered from indigenous populations in southern Illinois.

Cuttings were rooted in a vinyl chloride–covered rooting house at Corvallis, Oregon, according to rooting techniques known to work well with Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) cuttings (Copes 1983). The actual rooting bed measured 1.5 × 15 × 0.6 m (5 × 48 × 2 feet). The upper 15 cm (6 inches) was filled with a 2:1 rooting mix of sphagnum peat and fine washed sand, and the lower 46 cm (18 inches) was filled with fine sand. The rooting medium was maintained at 21 °C (70 °F) with heat cables. The rooting area was kept at high humidity, and the water needs of the cuttings and media were supplied by a single line of Flora-Mist nozzles (15 l/hr) (4 GPH nozzles) down the center of the bed. Nozzles were positioned 45 cm (18 inches) above the rooting medium and spaced every 91 cm (36 inches) along the center of the bed. The nozzles produced a full circle pattern. The on/off operation for the misting was controlled jointly by a 24-hour clock and a Mist-A-Matic® moisture-detecting electric leaf. The mist control was adjusted to spray for 12 sec whenever the moisture control device opened the solenoid valve regulating the water line. Intermittent misting began each day an hour after sunrise and ceased at sunset.

Six different fungicide foliar-sprays were used—a mixture of thiophanate-methyl and ETMT (Banrot), benomyl (Benlate), chlorothalonil (Bravo and Daconil), captan, iprodione (Rovral). A different one of these was applied each week during the rooting period. Biweekly applications of 20-20-20 fertilizer (200 ppm nitrogen) were applied by injector after roots were first visible on the basal area of the cuttings. Fertilization continued until the cuttings were removed from the rooting bed in August. High temperatures for air and rooting medium temperatures were controlled by externally covering the rooting house with 50% shadecloth.

Branch tips from rooted cuttings of 10 clones were collected in early April 1989. The branches were stored for 7 days at 1.6 °C (35 °F) in plastic bags containing moist paper towels until placement in the rooting bed. The buds were dormant at the time of collection. The cuttings were placed in the rooting chamber on April 25, 1989, after cuttings of all 10 clones were thoroughly mixed into one homogenous sample. Before placement, the 3- to 5-mm-diameter stems were trimmed to 15- to 20-cm (6- to 8-inch) lengths and submerged for 3 to 5 seconds in a 1%

solution of captan fungicide in water. The basal 2.5 to 5.1 cm (1 to 2 inches) of all cuttings were submerged for 5 seconds in 0.5% indole-3-butyric acid (5,000 ppm IBA) dissolved in 50% ethanol.

Immediately after the hormone application, the basal ends of the cuttings were stuck 5.1 cm (2 inches) deep into the rooting medium. The cuttings were positioned about 7.6 cm (3 inches) apart in three row treatments extending 13 m (42 feet). One row was 10 cm (4 inches) from the outside edge (outside row) of the bed 66 cm ((26 inches from the center), a second row (middle row) was 38 cm (15 inches) from the center and outside edge of the bed, and the third row was 2.5 cm (1 inch) from the center of the rooting bed (inside row) and also directly under the line of mist nozzles (figure 1).

The rooting bed was divided into 7 blocks; each block was 1.8 m (6 feet) long (figure 1). The experimental unit for rooting success was the percentage of 25 cuttings per row that rooted in each block. Available moisture decreased towards the exterior of the rooting bed as distance from the mist nozzles increased. At the end of the rooting period, the average moisture content of the rooting medium of each row was estimated by sampling eight locations along each row, weighing the rooting media samples before and after ovendrying, and calculating the percentage of water in the samples.

Rooting data were subjected to analysis of variance (ANOVA) by using the SAS procedures for general linear models (SAS Institute Inc. 1985). The experimental design had row position or moisture content of the rooting medium as the independent variable and rooting percentage the dependent variable. Blocking was done along the length of the rooting bed to reduce microsite variation. Such variation resulted from differences in soil history, misting application, air movement, etc. Data were transformed to angular values before ANOVA to correct for departures from normality. Significance was achieved when $P < 0.05$.

Results

Rooting of cuttings of baldcypress was greatest when cuttings were stuck in the wettest area (inside row) of the rooting bed (table 1; figure 1). Rooting averaged 58% for cuttings placed in the inside row, immediately below the mist nozzles. Increasingly poorer rooting occurred in the drier areas of the bed (33 and 6% for the middle and outside rows, respectively). Row difference (bed position) in rooting success was highly significant ($P < 0.0001$). Only block 4 had greater rooting in the midpoint row than in the wetter inside row (table 1). Block differences were not statistically significant.

Table 1—*Percentage of baldcypress cuttings that rooted and moisture in the rooting medium for cuttings grown in the outside, midpoint, and inside rows*

Block number	Outside row	Midpoint row	Inside row	Ave. rooting % ± SD
Rooting %				
1	8	16	56	27 ± 26
2	4	36	68	36 ± 32
3	0	40	80	40 ± 40
4	4	4	60	23 ± 32
5	4	44	60	36 ± 29
6	12	44	32	29 ± 16
7	8	48	52	36 ± 24
Average rooting % ± SD	6 ± 4	33 ± 17	58 + 15	32 ± 6
% Moisture in rooting medium	29	40	50	

Correlation coefficient for rooting percentage and moisture content (r = 0.995, $P > t$ = 0.0665). SD = standard deviation.

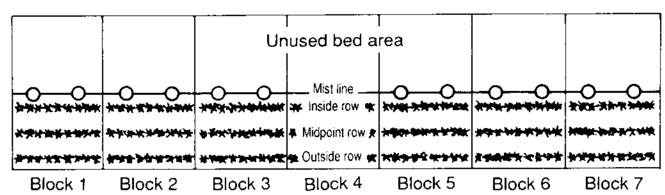

Figure 1—*Diagram of the rooting bed showing the relationship of the three treatment rows to blocking, mist nozzles, and edge of rooting bed.*

Available moisture declined as distance from the mist line increased. The inside row closest to the mist nozzles averaged 50% water content, and the midpoint row and outside rows averaged just 40 and 29%, respectively (table 1). The regression of rooting percentage on average moisture content was linear ($Y = -29.35 + 0.899X$), as indicated by the correlation between mean rooting percentage and moisture content of the rooting medium ($r = 0.995$). The probability of a larger T value occurring by chance was 0.0665.

Cuttings developed large tap roots at the base of each stem. The weight of the belowground biomass exceeded the aboveground component.

Discussion

We rooted baldcypress cuttings by using techniques and conditions that have worked well for Douglas-fir cuttings because we did not know the conditions that would promote greatest rooting of baldcypress stem-cuttings. Intermittent misting prevents desiccation of unrooted cuttings, but high humidity, moisture on the surface of the foliage, and warm temperature produce an ideal environment for the growth of pathogens. By not misting at night, we were able to keep the surface of the cutting dry during that time.

Optimum rooting conditions for baldcypress cuttings appeared to be wetter than for Douglas-fir (Copes 1992). Baldcypress rooted best in the wettest (50% moisture content) area of the rooting bed, while that area of the rooting bed, based upon prior experience, is the poorest location for rooting Douglas-fir cuttings. The driest area along the outside edge of the rooting bed (29% moisture content) was the poorest area for rooting baldcypress. Interestingly, the preferred rooting environments of baldcypress and Douglas-fir are similar to their general site requirements as seedlings. Baldcypress germination requires a soil that is saturated, but not flooded, for 1 to 3 months; seedlings can survive flooding if they grow fast enough to keep at least part of their crowns above water for most of the growing season (Wilhite and Toliver 1990). Douglas-fir seedlings are intolerant of excessively wet soils and die when subjected to more than 2 weeks of anaerobic conditions (McCaughey and Weaver 1991).

Baldcypress cuttings formed roots that where not characteristic of other conifers with which we have experience. A typical cutting developed a long, thick tap root that was 1 or 2 feet in length and literally grew out the bottom of the rooting bed. We have not seen similar root systems when rooting other conifer species. The characteristic root system may be an adaptive trait enabling baldcypress trees to anchor themselves in very wet sites.

Recommendations

Satisfactory rooting can be achieved with branch tips of 20-year-old baldcypress trees and the rooting procedures described here, but we feel that better rooting might have resulted if wetter conditions than those producing 50% moisture content in the medium had been used. Even greater rooting would probably have occurred if branch tips of more-juvenile trees had been used. In the future, propagators should test even wetter rooting conditions with 24 hours of intermittent or continuous mist. Care should be used in attempting to root or grow baldcypress cuttings in small containers as the large tap-root formed by the cuttings may not be well suited to shallow or small containers.

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Selecting Hybrid Poplars to Reduce Disease Risk May Also Reduce Biomass Yield

M. E. Ostry and W. E. Berguson

Research plant pathologist, USDA Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota and scientist, University of Minnesota, Natural Resources Research Institute, Duluth, Minnesota

Hybrid poplars representing 107 clones were screened for growth and resistance to Septoria musiva *to determine the cost, in terms of lost biomass, of reducing disease risk. Reducing the risk of septoria canker by selecting only highly resistant clones reduced biomass by as much as 26% after 3 years. Clones with parentage in the section Tacamahaca were generally the highest yielding; however, they were more susceptible to infection by* Septoria musiva *than clones in the section Aigeiros. When selecting poplar clones, growers need to balance growth potential with disease risk throughout the projected rotation period. Since tree death or stem breakage of susceptible clones frequently occurs, selection should be based primarily on canker resistance.* Tree Planters' Notes 44(3): 128–131; 1993.

Intensive culture of trees to provide woody biomass for a renewable source of energy is receiving much interest in several areas of the United States (Geyer and Melichar 1986). *Populus* species and hybrids are especially well suited for this intensive management because of their rapid growth, ease of vegetative propagation, coppice regeneration, and suitability for a wide range of sites.

Poplars are, however, susceptible to many biotic and abiotic damaging agents that can affect survival and growth of trees (Ostry et al. 1989b, Royle and Hubbes 1992). *Melampsora medusae* Thuem. (causing premature defoliation) and *Septoria musiva* Peck (causing stem cankers) have been the most serious pathogens of hybrid poplars in the north-central United States (Ostry and McNabb 1985). Research has shown that resistance to these pathogens varies greatly by clone.

No poplar clone can be considered immune from disease. Poplars are subject to accumulated stresses that can eventually predispose them to a succession of damaging agents. Adverse site and weather conditions, and other stress agents such as insect pests, can increase the incidence and severity of infection by one or more pathogens. Estimates of biomass yield by clone must include the potential impacts of disease to more accurately describe the suitability of individual clones (Abrahamson et al. 1990, Hansen 1990).

Information on yield and disease resistance of poplar clones from field trials will help growers decide which clones to plant to maximize biomass yield, while minimizing the risk of disease. The strategy of planting clone mixtures and the optimum number of clones to reduce the risk of disease in poplar plantations have been discussed (Libby 1982, Ostry et al. 1989a). Many high-yielding clones have good early growth but later are subject to stem breakage caused by septoria canker and cannot be coppiced because of the increased severity of canker on the stump sprouts compared to the single stems prior to harvest (Ostry et al. 1989a). Some of these clones, under certain conditions, may be grown on short rotations (< 10 years); the grower will have to replant with a different clone in the next rotation or else risk high stem mortality. Septoria stem cankers and the resulting stem breakage and tree death have led to plantation failure within 5 years after planting susceptible clones (Ostry et al. 1989a). Other clones have high resistance to disease, but yield less biomass than some of the more disease-susceptible clones (Ostry and McNabb 1985).

We screened a group of *Populus* clones for growth and resistance to *S. musiva* to determine the cost, in terms of lost biomass, of reducing disease risk by selecting only highly resistant clones. Because of the large number of clones included and limited field space, this trial was conducted in small row plots with the intent to derive relative yield rankings among the clones.

Methods

The study site, a cleared and drained peatland soil, was located in south-central Minnesota. Existing weeds were controlled with glyphosate (Roundup). Before planting, fertilizer was applied at a rate of 100, 50, and 100 kg/ha of nitrogen, phosphorus, and potassium, respectively. Weeds were controlled mechanically during the first 2 years after planting. Weed control was not necessary after canopy closure in the second year.

Unrooted hardwood cuttings of 107 *Populus* clones representing various species and hybrids were planted in May of 1983 in a randomized complete block design at a spacing of 1 by 1 m. Ten cuttings of each clone were planted in a row. Each clone was replicated three times within the plantation.

Development of biomass estimation equation. We estimated tree biomass using an equation of the following form:

$$\text{mass} = e^{a + b(\ln \text{diameter})} \quad [1]$$

The data on which this equation was based were collected by destructively sampling 40 trees from the plantation. Clones were first divided into four size classes to ensure that our sample encompassed the range of tree diameters present in the plantation. Ten trees from different clones in each size class were randomly selected and stem diameters at 15 cm aboveground were measured. Trees were cut and weighed green in the field and the total green weight recorded. Subsamples of bole and branches were collected and dried to equilibrium to determine moisture content. The total ovendry weight of the trees was then calculated.

Linear regression analysis was done using the linear form of equation 1: ln (mass) = a + b * ln(diameter). Both the slope and intercept were found to differ significantly from zero, with *P*-values associated with both parameters less than 0.001. Parameter estimates are 2.40 and 3.51 for the slope and intercept, respectively. The R^2 of this equation after transformation of data to original scale is 0.95.

Clone yield estimation and adjustment for competition. We used equation 1 to estimate the biomass of all trees on a plot. Although most of these trees were single-stemmed, in some cases more than one primary stem was present. In those cases, the biomass of all stems in the clump was estimated and the total clump biomass calculated. We calculated the mean tree or clump mass of the plot accounting for mortality and expressed yield as megagrams per hectare (Mg/ha) [1 Mg = 1,000,000 g = 1,000 kg].

Because the plot configuration used in this study was a single row of 10 trees, the effects of differences in competition on estimates of clone yield was considered. We used analysis of covariance to determine the effect of adjacent plot yield and the parameters associated with those effects (Berguson and Grigal 1988). We tested the effect of plots in the four cardinal directions from each plot on which yield was being estimated. Plots adjacent to the ends of the plot had no significant influence on yield because little shading occurred ($P > 0.10$). Of the two adjacent plots parallel to each plot in question, the mass of the plot north of the plot in question was found to have a significant influence on yield with the coefficient being −0.22. The negative sign indicated that adjacent plot mass decreased the mass of the plot in question. The adjacent plot to the south did not significantly affect yield (P = 0.16). We tested for homogeneity of slopes and found no significant interaction between clone and any of the covariates ($P > 0.40$). This indicated that clones responded in the same way to competition and an adjustment for competition was possible across all clones. Analysis of covariance to adjust all clones to the mean level of competition (grand mean mass) was done using the following formula:

$$\text{mass}^{adjusted} = \text{plot mass} + (\text{mean mass} - \text{adjacent mass}) * -0.22) \quad [2]$$

In the case where a clone was adjacent to a clone having a mass higher than the grand mass, the adjustment of the plot in question was positive and the estimated yield increased. In order to make estimated yields more accurately reflect yields likely attainable in a monoculture of a particular clone, we used the yield of the plot itself in place of the adjacent plot and adjusted the yield as if the clone was in a single-clone plantation. With high-yielding clones this reduced their estimated yield, providing a more realistic estimate of plantation yield than would be the case using the adjustment shown in equation 2.

Incidence and severity of foliage and stem diseases were recorded in the fall of 1985. Estimates of melampsora leaf rust were obtained using a combined score based on severity of leaf infection and the percentage of leaves affected (Schreiner 1959). Because severe winter dieback was associated with premature defoliation caused by leaf rust ($P < .01$), severely affected clones were eliminated from further analyses. Of the 13 clones eliminated, 11 of them were *P. deltoides* × *P. trichocarpa* hybrids. All remaining trees were rated for septoria stem canker and placed in one of the following risk classes: 0 = no cankers, 1 = trees on 1 plot with stem cankers, 2 = trees on 2 plots with stem cankers, 3 = trees on all 3 plots with stem cankers. We estimated combined biomass yields of the 10 highest yielding clones without regard to canker risk (risk classes 0, 1, 2, or 3) and of the highest yielding clones resistant to septoria canker (risk class 0).

Results and Discussion

Survival, growth, and disease resistance varied among clones. The estimated 3-year biomass yields of the surviving clones ranged from 1.3 to 38.8 Mg/ha. Pathogens affecting trees other than *Melampsora medusae* were *Marssonina brunnea* (Ellis & Everh.) Magnus, which caused a leaf anthracnose; *Venturia macularis* (Fr.:Fr.) E. Müller and Arx, which caused a leaf and shoot blight; and *Agrobacterium tumefaciens* (Smith and Townsend) Conn, which caused crown gall. None of these other pathogens caused as severe a disease problem as *S. musiva* and were not considered limiting in our study.

There was a strong clonal pattern in regards to infection by *S. musiva*. In almost all cases, trees within a plot either were all healthy or all affected by stem cankers. However, occasionally not all plots of each clone were affected. This may have been due to the trees of these plots being bordered by either resistant or severely diseased trees with a corresponding decrease or increase in inoculum. Additional research is needed on the effects of clone mixtures on disease incidence and severity. Planting random mixtures of resistant and susceptible *Populus* clones did not reduce the incidence or severity of septoria canker on highly susceptible clones in three plantations in Michigan (Ostry et al. 1989a). Planting hybrid poplar clones in mosaics of pure clonal blocks that can be managed as independent units if it becomes necessary because of a disease outbreak among susceptible clones is one way to minimize disease risk (Ostry and McNabb 1990).

The estimated biomass yield of the 10 highest yielding clones in the two groupings based on canker risk illustrates the effect that selecting for canker resistance has on potential biomass yields (tables 1 and 2). In the examples used in this study, reducing the risk of septoria canker by selecting only highly resistant poplar clones (risk class 0) reduced potential biomass yield. The 10 highest yielding clones that were completely free of canker (table 1) produced a combined estimated mean yield of 22.9 Mg/ha. This was 26% less biomass than the estimated mean yield of 30.9 Mg/ha produced by the 10 highest yielding clones that were selected without regard to canker susceptibility (table 2). Clone DN 3, however, was resistant to septoria canker and also one of the highest yielding clones.

Of the highest yielding clones without regard to canker susceptibility, all but 3 had at least one parent in section Tacamahaca (balsam poplars). In contrast, only 2 clones highly resistant to septoria canker had parents from the section Tacamahaca. The majority of the resistant clones had parents from the section Aigeiros (cottonwoods and black poplars). This is further evidence that although hybrids involving poplar species from the section Tacamahaca have rapid early growth, they are more susceptible to septoria canker than poplars in the section Aigeiros (Ostry and McNabb 1985). Additional field tests are needed on a wide range of sites to determine if site differences will affect clone selection based on reducing canker risk.

Table 1—*Combined estimated 3-year biomass yields of the 10 highest yielding* Populus *clones resistant to septoria canker (south-central Minnesota, 1983–1985)*

Clone	Parentage	Estimated adjusted mass (Mg/ha)	Canker risk class
DN3	*P deltoides* × *P. nigra*	31.0	0
NE10	*P. nigra* × *P. trichocarpa*	24.9	0
NE20	*P. nigra* var. *charkowiensis* × *P. nigra* var. *caudina*	23.8	0
S264	*P. deltoides* var. *angulata* × *P. nigra* 'Volga'	22.5	0
NE383	*P. nigra* var. *betulifolia* × *P. trichocarpa*	22.2	0
NE222	*P. deltoides* × *P. nigra* var. caudina	22.0	0
8MIRD	Unidentified Aigeiros clone	21.3	0
DN9	*P. deltoides* × *P. nigra*	20.8	0
DN96	*P. deltoides* × *P. nigra*	20.7	0
NE259	*P. deltoides* var. *angulata* × *P. nigra* var. *incrassata*	19.4	0
Mean biomass yield		22.9	

0 = no stem cankers on trees in any plots.

Table 2—*Combined estimated 3-year biomass yields of the 10 highest yielding* Populus *clones without regard to septoria canker (south-central Minnesota, 1983–1985)*

Clone	Parentage	Estimated adjusted mass (Mg/ha)	Canker risk class
L296	Unidentified *P. trichocarpa* hybrid	38.8	3
NE320	*P. nigra* var. *charkowiensis* × *P. trichocarpa*	32.7	3
NE32	*P. deltoides* var. *angulata* × (*P.* × *berolinensis)*	32.5	1
DN3	*P. deltoides* × *P. nigra*	31.0	0
DN29	*P. deltoides* × *P. nigra*	30.1	3
NE55	*P. candicans* × (*P.* × *berolinensis)* 'Maine'	29.9	3
NE50	*P. maximowiczii* × (*P.* × *berolinensis)* 'Oxford'	29.6	3
NE252	*P. deltoides* var. *angulata* × *P. trichocarpa*	28.8	3
L239	Unidentified *P. trichocarpa* hybrid	27.7	3
H48	*P. deltoides* × *P. nigra*	27.6	1
Mean biomass yield		30.9	

0 = no stem cankers on trees in any plots, 1 = trees on 1 plot with stem cankers, 2 = trees on 2 plots with stem cankers, 3 = trees on all 3 plots with stem cankers.

Conclusions

Growers can reduce the risk of serious damage to trees from septoria canker by planting the resistant clones that are now available. However, this reduced risk may have an associated cost in the form of a potential biomass yield reduction. Reduced yield may lower economic returns, but on the other hand, reduced risk of disease guards against potential catastrophic losses later in the rotation. It is likely that the resistant clones would eventually produce higher biomass yields on longer rotations than the susceptible clones because of future stem breakage of the severely diseased trees. *Populus* tree breeders must use resistance to *S. musiva* as one of the major selection criteria in order to provide clones suitable for use in the north-central and northeastern United States.

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