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Abstract

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This proceedings is a compilation of 30 papers that were presented at the regional meetings of the Forest and Conservation Nursery Associations in the United States in 2003. The **Western Forest and Conservation Nursery Association** meeting was held at the Coeur d'Alene Inn in Coeur d'Alene, Idaho, June 9 to 12. The meeting was hosted by the USDA Forest Service, Coeur d'Alene Nursery. Morning technical sessions were followed by field trips to Coeur d'Alene Nursery, restoration outplantings on the Coeur d'Alene Indian Reservation, and Plants of the Wild Nursery. The **Northeastern Forest and Conservation Nursery Association** meeting occurred July 14 to 17 at the Crown Plaza Hotel in Springfield, Illinois. The meeting was hosted by the Illinois Department of Natural Resources, Mason State Nursery. In addition to technical sessions, a tour of the Mason State Nursery was included. Subject matter for both sessions included nursery culturing, harvesting, and storage; fertilization; seed transfer, collection, and processing; and native species propagation.

Keywords: bareroot nursery, container nursery, nursery practices, fertilization, pesticides, seeds, reforestation, restoration, plant propagation, native plants, tree physiology, hardwood species

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

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** *No papers received; for more information contact authors at the address provided in the list of participants.*

Western Forest and Conservation Nursery Association

Coeur d'Alene, ID

June 9–12, 2003

Container Seedling Storage and Handling in the Pacific Northwest: Answers to Some Frequently Asked Questions

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In: Riley, L. E.; Dumroese, R. K.; Landis, T. D., tech coords. National proceedings: Forest and Conservation Nursery Associations—2003; 2003 June 9–12; Coeur d'Alene, ID; and 2003 July 14–17; Springfield, IL. Proc. RMRS-P-33. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Abstract: The paper contains a list of 20 questions that seem to arise often in discussions involving storage and handling of container (and bareroot) planting stock. Each question is stated, followed by a response. The questions span a wide range of topics including time of lifting, methods of storage, thawing rates, and effects of storage on seedling quality.

Keywords: freezer storage, cooler storage, carbohydrate reserves, root hardiness, stress resistance, lifting window, under-snow storage, chilling, dormancy

Introduction

For more than 25 years, I have been actively engaged in seedling quality research and operations. Every year the same questions seem to arise around lifting and planting time. These questions relate to various aspects of seedling handling and storage. This meeting of the Western Forestry and Conservation Nursery Association provides an excellent forum at which to provide responses to these questions to a wide audience. Further, their publication in these proceedings will ensure that they are both available and accessible to regeneration personnel in future years.

What Are the Main Methods for Storing Container Stock?

There are essentially 2 methods for storing both container and bareroot planting stock: cooler storage and freezer (or frozen) storage. In cooler storage, stock is held at slightly above freezing—typically +1 °C (34 °F). In contrast, in freezer storage, the temperature is slightly below freezing—typically –1 °C (30 °F). Although separated by only a degree or two, these 2 regimes can have profound effects on seedlings, as we shall see later. One method of cooler storage that was once popular in the Pacific Northwest was "open-bin" storage. Here seedlings were placed into open-topped bins, rather than storage bags or boxes, and held in a large cooler. Generally they were watered to keep them moist throughout the storage period. This method is seldom used today. A variant of freezer storage that is used in parts of Canada and Scandinavia is "under-snow" storage. Containers are placed outdoors on the ground in fall. When covered with snow they can be held at just below freezing throughout the winter months. This method can be very successful and involves low cost.

Is Under-Snow Storage Risky?

Yes, it can be. If snow fails to materialize, stock can suffer from cold damage—especially to the root systems. Although roots do attain a certain level of cold hardiness in winter, they do not harden nearly as much as shoots. Therefore, containerized seedlings are particularly vulnerable to this kind of damage. State-of-the-art snowmaking machines have greatly reduced this risk, but they are expensive. Other speakers at this meeting will address "under-snow" storage more completely.

Is Container Stock Stored Differently Than Bareroot Stock?

Not really. Although there are vast differences in equipment—storage bag designs, handling systems, and the like—the biology of both stock types is very similar. Therefore, storage methods and stock responses to storage are very similar. However, there is one important exception. Container stock tends to be more forgiving than bareroot stock.

How Is Container Stock Storage More Forgiving?

Assuming that container stock is stored with the plug mass intact, this provides a protective cushion around the root system. It buffers the sensitive roots from rapid changes and extremes in temperature and moisture. Further, the plug mass protects the roots to some extent from rough handling and other kinds of physical abuse. But perhaps the main advantage of container stock is that, since it is not grown in the ground, various weather-imposed lifting limitations can be avoided. Frozen ground, rain, mud, and other factors that close the lifting window for bareroot stock are not an issue with container seedlings. It should be possible for growers to lift and pack container stock at the optimum time.

How Do You Determine the Optimum Time for Lifting Container Stock for Storage?

Here are a couple of rough guides for determining the date of lifting for containers:

Freezer Storage

For long term freezer storage (2 to 6 months), wait until the stock has been exposed to about 350 hours of chilling (when temperature is below 42 °F [5.6 °C]). This will ensure that the roots are hardy enough to survive prolonged frozen conditions (Lindstrom and Stattin 1994; Stattin and others 2000). We'll talk more about this later.

Cooler Storage

For shorter term cooler storage, chilling time can be relaxed to about 300 hours.

No Storage

If storage is not involved (that is, lifting for "hot planting") these rules do not pertain and stock can be lifted when it is not actively growing.

In General, How Does Storage Affect Container Stock?

In order to answer this question we need to consider 2 things: 1) how environmental conditions in storage differ from those in the greenhouse or growing area; and 2) how these differences affect seedling physiology.

In greenhouse or outdoor conditions, seedlings are exposed to: 1) daily input of radiant energy as sunlight; 2) daily photoperiod; 3) strong diurnal variations in temperature; and 4) strong diurnal variations in humidity. Contrast this to storage where seedlings experience a prolonged period (perhaps several months) of constant darkness, low temperature, and high humidity.

How Do Plants in Storage Respond to Prolonged Constant Darkness?

First, there is no photoperiod signal to trigger plant growth responses to environmental cues. Fortunately, this does not seem to be a problem. The short day signal that induces dormancy in plants occurs in the greenhouse during summer (Perry 1971). Dormancy release in storage is triggered by chilling, not photoperiod, so the absence of a photoperiod in storage is of little consequence. Second, a far more important issue is the lack of radiant energy for photosynthesis. Seedlings, even when frozen, remain alive in storage. Therefore they continue to metabolize and respire energy (Ritchie 1982). With no photosynthesis occurring, this energy must be obtained from stored carbohydrates. Therefore, the plant must persist through storage on only the carbohydrate it has stored before it was lifted.

How Much Carbohydrate Reserve Is Present When Stock Is Placed in Storage?

Generally, seedlings contain between 150 and 200 mg/g dry weight (15 to 20%) of total nonstructural carbohydrate (TNC) at the time they are lifted in winter. TNC is the carbohydrate fraction that can be burned as food by seedlings. It includes mainly sugars and starch, and does not include cellulose or lignin. During winter, various plant tissues contain different levels of this material, with the highest concentrations occurring in the foliage (Figure 1).

How Rapidly Is This Food Reserve Depleted?

Rate of depletion depends largely on temperature, since respiration has a Q_{10} of slightly above 2.0. Even though cooler storage is conducted at only about 1 to 2 °C (2 to 4 °F) higher than freezer storage, this small temperature difference, over time, is enough to cause more rapid TNC depletion in the cooler than in the freezer. Coastal Douglas-fir seedlings that were held in freezer storage depleted 17 and 28% of their stored TNC after 2 and 6 months, respectively (Figure 2). Cooler-stored trees lost 28% after only 2 months.

What Carbohydrate Concentration Is Critical for Survival?

Unfortunately, I cannot give you a definitive answer to this question. However, there is evidence suggesting that levels as low as 10 to 12% may be near critical. Clearly, TNC levels this low will affect growth performance during the first year after planting. To what extent it affects survival is not known.

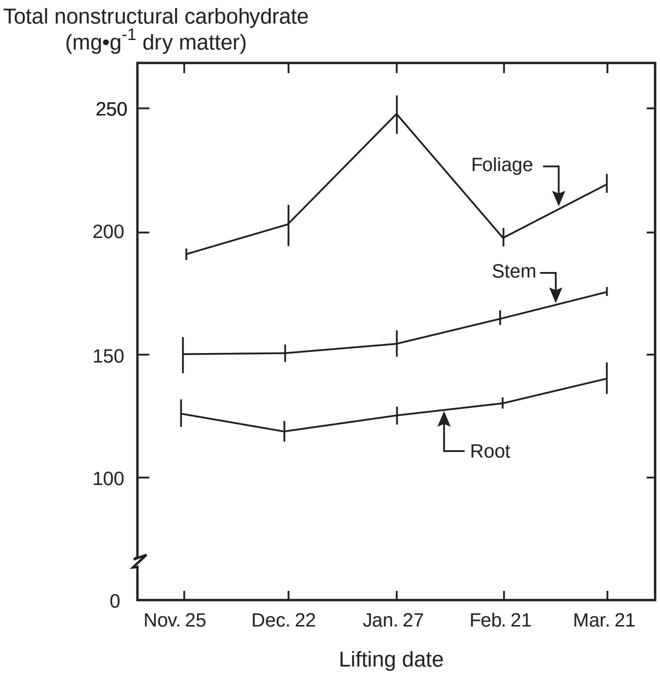

Figure 1—Total nonstructural carbohydrate concentrations in coastal Douglas-fir seedlings during a winter lifting season. Vertical bars are ± 1 SE (redrawn from Ritchie 1982).

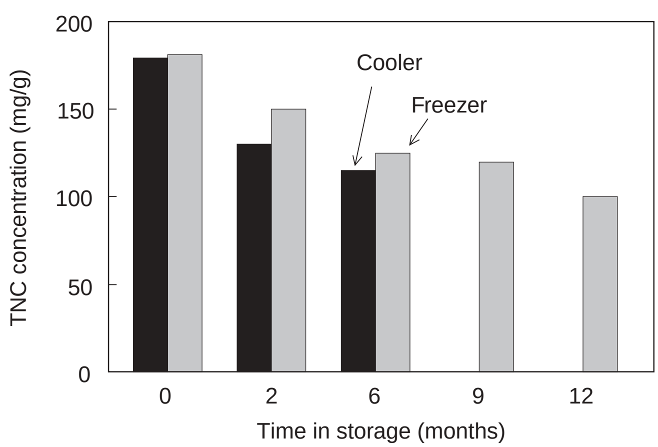

Figure 2—Concentration of total nonstructural carbohydrate in coastal Douglas-fir seedlings. Seedlings were lifted midwinter and placed in either cooler (+1 °C [34 °F]) or freezer (–1 °C [30 °F]) storage for 2, 6, 9, or 12 months (modified and redrawn from Ritchie 1982).

How Does Exposure to Prolonged Cold Affect Seedlings in Storage?

Prolonged cold acts as chilling and, therefore, promotes (van den Driessche 1977), but slows (Ritchie 1984) the release of dormancy. This is because the optimum temperature for dormancy release is 3 to 5 °C (37.5 to 41 °F) (Anderson and Seeley 1993), and storage occurs at a lower, hence less efficient, temperature (Figure 3). Because of this effect, seedlings taken out of storage in say, April, will be much more dormant and stress resistant than those growing in the nursery in April. This is a positive benefit of storage. The other side of this coin is that prolonged freezer storage can injure roots if the plants are not sufficiently cold hardy when they are placed into freezer storage (Stattin and others 2000).

How Does Freezer Storage Kill Roots if the Storage Temperature Is Above the Lethal Temperature for Roots?

Root tissues, like all plant tissues, are compartmentalized into what are called the "apoplast" and the "symplast." The apoplast consists of intercellular spaces, cell walls, and xylem elements. Water in the apoplast is nearly pure so it freezes rapidly. The symplast includes the tissues inside the cell membrane. Symplast water, or cell water, contains dissolved and colloidal material that give it a lower freezing point. When tissue freezes, ice crystals form in the apoplastic water. These crystals, having a very low water potential, draw water out of the cells. This lowers the freezing point of the symplast and both tissues enter an equilibrium state. When the tissue thaws, the ice crystals melt and water moves back into the cells. This is a natural process that can occur daily in winter and does not damage a hardy plant. But in freezer storage there is no thawing, so the ice crystals continue inexorably to grow. Over time this dehydrates cell contents to the extent that they are irreparably damaged. At this point root tissue begins to die.

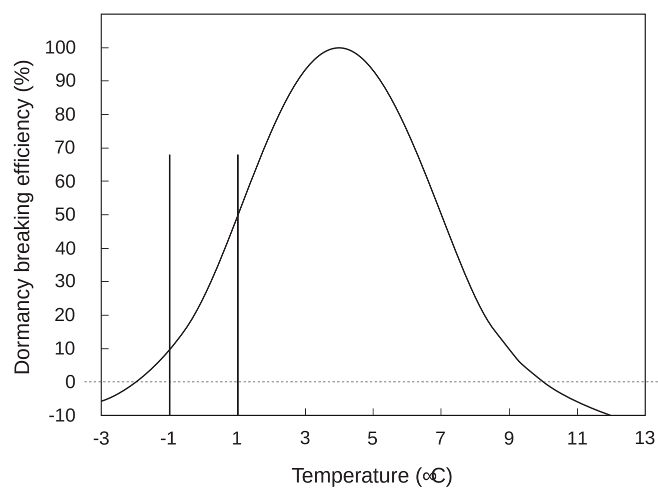

Figure 3—Relative dormancy-breaking efficiency of temperatures between –3 and +12 °C (27 and 54 °F). Seedlings are typically stored between –1 and +1 °C (30 and 34 °F). While temperatures in this range release dormancy, the rate of release is slowed owing to their low efficiency (modified and redrawn from Anderson and Seeley 1993).

How Does Constant High Humidity Affect Seedlings in Storage?

High humidity presents a “good news:bad news” situation to seedlings. The good news is that the constant high humidity in storage bags normally prevents the seedlings from desiccation. This, of course, is very important for stock quality. On the other hand, high humidity presents an opportunity for various storage molds and root diseases to proliferate and compromise stock quality. As a general rule, freezer storage arrests the proliferation of mold and disease on stored stock; cold storage does not.

How Does Cold Storage Affect Cold Hardiness?

This is a very important question because if storage impedes or arrests the development of winter hardiness, then stock lifted early and planted out in midwinter may not be hardy enough to survive low temperatures on the planting site. Unfortunately, I know of no published studies that address this question in a focused, systematic way, so I cannot give a definitive answer. This would make an excellent research topic for a Masters or Ph.D. student.

How Long Can Container Stock Be Stored?

Here are 2 “Rules of Thumb” that I have found useful in answering this question: 1) stock that is lifted early (say, before January) can be successfully freezer stored for up to 6 months; 2) stock should be cooler stored for no longer than 8 weeks no matter when it is lifted. This primarily reflects the mold/disease issue mentioned above.

What Factors Determine Whether You Should Freeze or Cooler Store Container Stock?

The most important factor is probably the availability of a freezer storage unit. Many operators do not have access to these expensive facilities. If such a unit is available, then the key factors are lifting date and desired storage duration. Stock that is lifted early can be either freezer or cooler stored. Late-lifted stock, having lost cold hardiness, is best stored at slightly above freezing. If the desired storage duration is more than 8 weeks, freezer storage should be used. For shorter term storage either method can be used.

How Rapidly Should You Thaw Frozen Container Stock?

The conventional wisdom on this subject is that stock should be thawed very slowly. This is wrong. Thawing rates of frozen stock are very uneven. Seedlings on the outer edges of boxes or pallets will thaw much faster than those in the middle. During this time detrimental things are happening to the thawed seedlings. Heat of respiration is building up; stock is dehardening and rapidly losing stress resistance, exhausting its already depleted remaining food reserves, and possibly desiccating. Also, storage diseases have a perfect environment in which to proliferate. So it is important to keep the thawing period as brief as possible (Camm and others 1995).

Can You Plant Frozen Plugs?

Yes. Studies on several species have shown that plugs can be planted in a frozen condition with no ill effects (Kooistra and Bakker 2002; Kooistra 2004).

Can Stock Be Refrozen Once It Has Been Thawed?

It is not uncommon for foresters to thaw frozen stock for planting only to find that the planting site has been snowed in, or that some other problem prevents the stock from being planted when planned. What to do—refreeze it or put it in the cooler? Neither option seems very tenable. However, my suggestion would be to refreeze the stock if the planting date is unknown or several weeks away. If it is certain that planting will be delayed for only a few days, then cooler storage may be preferable. This is based on assumptions only, and not on good research data. To my knowledge this specific question has not been addressed in a published report. This would make another good student research project.

How Should You Handle Late-Lifted Plugs?

Very carefully. In my experience, late lifting (generally after February) can become very risky. At this time stock is rapidly dehardening, losing stress resistance and beginning to grow (Ritchie 1989). If you find yourself in a situation when late lifting is unavoidable, it is critical to lift, handle, and store stock with extreme care.

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Container Seedling Handling and Storage in the Rocky Mountain and Intermountain Regions

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Abstract: An overview of the Rocky Mountain Native Plants Company (RMNP) and its container production program is presented. Descriptions are given of the greenhouse, woody plant nursery, bareroot nursery, and other programs at RMNP. Discussion is also provided concerning the effect of potting containers on root formation.

Keywords: container nursery, native species

Overview

Rocky Mountain Native Plants Company (RMNP) was founded in 1997 as a private conservation nursery specializing in site specific native plant production for the Rocky Mountain Region. The company is on the western slope of the Rocky Mountains in Rifle, Colorado, near Glenwood Springs. Their employment is approximately 22 full-time individuals, with staff increasing seasonally to include an additional 20 employees as installation, field, and greenhouse personnel. The nursery is situated on a 74.6-ac (30.2-ha) site in Garfield County with native soil conditions consisting of predominantly silty loam.

The annual production of RMNP consists of approximately 1.5 to 3 million plants, comprised of nearly 350 species, 100% of which are indigenous to the Central Rocky Mountain and Intermountain Region. Facilities include 16 greenhouses of various sizes and construction, a 17-ac (7-ha) container nursery, a 5-ac (2-ha) bareroot nursery, and a 10-ac (4-ha) cultivated and linear wetland nursery.

Container Production

RMNP container soils consist of a mixture of peat, coir, perlite, vermiculite, and scoria with micronutrients, gypsum, and *Gliocladium* added. Soil mixes vary according to species type and hydrologic preference. In addition, mycorrhizae or *Frankia* (specifically for *Purshia, Shepherdia*, and *Alnus*) are added to soil mixes for many woody species.

Water is derived primarily from Harvey Gap Reservoir, and secondarily from the Colorado River. All greenhouse water is processed through reverse osmosis, then ozonation.

Most woody species are produced in 5-gal (19-l), 1-gal (4-l), 1-qt (1-l) containers, and 10-in^3 (164-cc) Ray Leach SuperCells™. In addition, selected woody species are produced by bareroot propagation in seed beds, with the number of species as well as the total number of plants produced per species increasing by the year. Forb species are produced in 1-gal containers and 10-in^3 cells. Graminoids are primarily produced in 10-in^3 cells, with 1-qt and 1-gal materials produced for selected wetland species. Winstrips in 5.5-in^3 (90-cc) containers, as well as plants in 3-in^3 (50-cc) containers, are grown by contract only.

Production Protocol

RMNP site collects as many of its seed types as possible to ensure that they reflect the genetic sources most common to the respective watersheds of their area. Seeds are pretreated to break dormancy, then germinated in a propagation house for approximately 6 weeks. For cutting stock, cuttings are taken at the appropriate time of the year (often spring or fall), then placed under fog irrigation until rooted. Normally germination is accomplished in miniplugs—288-cells for forbs and woody species and 521-cells for graminoid species.

Once adequately rooted, materials are moved to a holding house under overhead irrigation. These materials are normally held for not more than an 8-week period. Materials are then transplanted into SuperCells™ and moved into bottom-heated, gutter-connect structures. Materials are held in these structures for an average of 12 weeks. Herbaceous materials (graminoid and forb) are moved "as is" to cold frames. Woody materials are transplanted to 1-qt (1-l) containers and moved to cold frames. Cold frames are covered with double layer polyethylene during the winter or shadecloth and insect netting to facilitate interstate certification and transport during spring, summer, and fall. Heaters are used within the cold frames to maintain winter temperatures above 38 °F (3 °C). After 1 year as 1-qt materials, woody plants are transplanted to 1- and 5-gal (4- and 19-l) containers, depending on market demand, and then moved to a container nursery.

Additional Considerations

For many applications, RMNP prefers to utilize 1-qt (1-l) materials in preference to 1-gal (4-l) materials, since the 1-qt materials cost approximately 50% less than 1-gal materials. In addition, 1-qt materials are easier to handle and transport. A case of 25 1-qt containers occupies approximately 2 ft^2 (0.2 m^2) versus 8 1-gal containers/2 ft^2. Finally, 1-qt containers have an approximately 9-in (23-cm) rooting depth versus 1-gal containers having a 6-in (15-cm) rooting depth, allowing better access to groundwater and improved erosion control. Conversely, 1-gal materials have better resistance to predation and alkalinity.

For similar reasons, RMNP prefers to use SuperCells™ over F-32 (2.25 x 2.25 x 2.25 in [6 x 6 x 6 cm]) containers. The rooting depth of the SuperCells™ is almost three times greater than the F-32 containers, allowing greater accessibility to groundwater and increased resistance to erosion. Finally, 10-in^3 cells fit 98/1.5 ft^2 (0.14 m^2) versus 2.25 containers fitting 32/1.5 ft^2.

RMNP prefers the darker container color of the recycled Super Cells over the traditional white or lighter colored cells. The light colored cells allow enough light transmittance to cause a greening of rhizomes and an eventual degradation of the affected roots. RMNP staff have also noticed reduced moss and liverwort problems with the darker containers. In addition, the darker containers are made from recycled plastic.

Container Handling and Storage in Eastern Canada

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Abstract: Sowing, culturing, and overwintering methods of the 3 largest forest nurseries in Atlantic Canada are discussed. Methods vary from a smaller, hands-on approach to the highly mechanized operations of a private industrial nursery.

Keywords: container seedlings, frost protection, cold protection

Introduction

In order to compare and contrast nursery practices, a few little known facts about Canada, and eastern Canada specifically, should precede a discussion of nurseries in Atlantic Canada. Throughout Canada, approximately 75% of the population lives within 100 mi (160 km) of the US border; approximately 80% of the population lives in large cities.

Nova Scotia and New Brunswick nurseries will be the main topics of this discussion. Nova Scotia and New Brunswick are located east of northern Maine; Nova Scotia is the small piece of land sitting out in the Atlantic Ocean. Nova Scotia is approximately 21,500 mi^2 (55,700 km^2) in size, or half the size of Florida. The province has 4,800 mi (7,725 km) of coastline and supports a population of less than 1 million. The capital of the province is Halifax, with a population of approximately 350,000. Nova Scotia is also the home of the famous sailing vessel, the Bluenose.

Nova Scotia Nursery Operations

In 2002, 23 million trees were planted throughout the province. Approximately 50% of the seedlings were grown in Jiffy pellets, comprised of gauze mesh and peat substrate (Figure 1). The remaining 50% were grown in Multipot hard wall containers (Figure 2).

All seeds sown for Nova Scotia Department of Natural Resources (DNR) originate from seed orchards. DNR also sells improved seeds to private nurseries; the goal is deployment of these seeds as quickly as possible. DNR seed orchards consist predominantly of *Picea mariana* (black spruce), *P. rubens* (red spruce), *P. glauca* (white spruce), *P. abies* (Norway spruce), *Pinus strobus* (eastern white pine), and *Abies balsamea* (balsam fir) for Christmas tree production.

Strathlorne Forest Nursery

Strathlorne Forest Nursery is operated by Nova Scotia DNR, and is located on Cape Breton Island. The nursery grows 12 million containerized seedlings per year.

Sowing—The key to a successful nursery operation is an efficient seeding operation. Strathlorne Nursery has invested large amounts of time and money on research and extra staff to lower seed usage as much as possible. The current seed usage, on average, is 1.2 seeds per cell; high value seeds, such as Norway spruce, are single seeded.

The seeding operation involves a variety of steps, requiring both mechanized and human labour. Jiffy pellets are shipped "ready-to-sow" on pallets directly from the factory. These containers are positioned in a seed line operation, where a template is placed over the pellets to direct seeds into the cavity for germination (Figure 3). Prior to sowing, the seeds are coated with a paint pigment to make them easier to see during inspection and during any necessary hand sowing. All seeding, for both Jiffy pellets and Multipots, undergoes inspection and hand seeding prior to the placement of containers in the greenhouses. This has reduced seed usage by 40%, and has resulted in a dramatic reduction in thinning and transplanting costs.

Figure 1—Seedling grown in a Jiffy pellet.

Figure 2—Multipot 2-67™ hard wall containers.

Figure 3—Initiation of seeding operation, with template placed over the Jiffy pellets.

Figure 4—Jiffy pellets placed into a container for transport and culture in the greenhouse.

Following seeding, the pellets are run through a fine water spray so the seeds will "stick" in the cavity. The pellets are then placed into a growing container at 2 pellet sheets per container (Figure 4). A light coating of very fine vermiculite is placed over the seeds. This helps prevent the collapse of the seed cavity if a watering volume mistake occurs.

Seeded trays are moved to the greenhouses on electric conveyors and placed on racks for germination and culturing.

Extended Greenhouse Culture—All crops in eastern Canada use "Extended Greenhouse Culture" (Colombo 1997). Crops are held in greenhouses at elevated temperatures until early November. At the end of the growing season in early November, all crops are tested at the University of New Brunswick for cold hardiness. Two successive tests at –15 °C (5 °F) are done prior to moving crops out of the greenhouse. If cold hardiness has reached an acceptable level, seedlings are moved outside for overwintering.

Greenhouse crops are moved on multiple layered wagons to holding areas for overwinter protection (Figure 5). This reduces the number of tractors and wagons required to move crops.

Figure 5—Transport of seedlings to overwinter holding areas on multiple layered wagons.

Figure 7—Covering the crop with plastic for overwintering.

Overwintering Methods—

Pallets and Plastic: The most successful method for overwintering seedlings at Strathlorne Nursery has been a combination of pallets and plastic. Root growth potential tests have shown very good results with this method.

Following removal from the greenhouse, crops are placed on pallets for further hardening-off. For overwintering, the crops are placed on the ground with concrete blocks positioned throughout the crop. Pallets are then placed above the crop, supported by the concrete blocks (Figure 6). The crop is sealed with 6-mil white plastic (Figure 7); the plastic is attached with wooden strips, with the edge of the plastic covered with gravel to hold it in place.

The plastic remains on the crop until late March or early April of the following year. The rule of thumb used for the timing of plastic removal is to begin the process when the plugs are completely thawed in the spring.

Cold Protection Fabric: An alternative method to the plastic and pallets is the use of a cold protection fabric placed directly over the seedlings. Arbor Pro, a product made in Quebec, is a fabric similar to felt that comes in different thicknesses. The fabric used at the nursery is approximately 0.19 in (0.5 cm) thick. The fabric is pulled over the crop and held in place with concrete blocks along the edges (Figure 8).

Packing and Shipping—

Root Pruning: Root pruning for seedlings grown in Jiffy pellets must be done at least 3 weeks prior to shipment for planting. White and Norway spruce seedlings are usually cut in late summer or early fall to ease the workload in the spring. Black and red spruce seedlings are pruned prior to shipment. In the past, root pruning was done on a manual jiffy cutter. This process is now accomplished on a newer electric dual cutter.

Grading: Crops that cannot be shipped "as is" are subjected to a grading process prior to shipment. The quality rule in Nova Scotia is that 90% of the tree seedlings in a container must meet quality standards for height, root collar diameter, green foliage, free of insect/disease, and so on.

Figure 6—Pallets supported by concrete blocks over the crop for overwintering.

Figure 8—Arbor Pro recently removed from crop. Note that no damage has occurred to the crop. Although laid over from the weight of snow, the seedlings will stand up within a couple of weeks.

Grading at the nursery is done on the old bareroot grading tables, with a conveyor added to move the containers to the graders. The graded trays are placed on pallets inside the grading room, pushed outside to a holding area awaiting shipment, and then moved by forklifts for loading.

Shipment: Shipment to the planting sites is accomplished by using 5 ton trucks and tractor/trailer units. The capacity of the 5 ton trucks is 80,000 seedlings. However, the nursery has recently purchased a "Kentucky" trailer, which has a series of 7 doors down the side; the maximum distance to unload trees is 8 ft (2.4 m) versus 50 ft (15 m) in a regular trailer (Figure 9). The capacity of this unit is 260,000 seedlings.

New Brunswick Nursery Operations

In 2002, 65 million trees were planted throughout the province. Approximately 30% of the seedlings were grown in Jiffy pellets; the remaining 70% were grown in Multipot hard wall containers. More Multipots are used in New Brunswick than Nova Scotia, as 1 large industrial nursery grows 32 million Multipot seedlings per year.

All seeds sown in New Brunswick nurseries originate from seed orchards. Second generation seeds are used for black spruce and *Pinus banksiana* (jack pine); first generation seeds are used for all other species.

Kingsclear Forest Nursery

Kingsclear Forest Nursery is operated by New Brunswick DNR, and is located in Fredericton, NB. The nursery grows 18 million containerized seedlings per year in 3 separate crops; all seedlings are grown in Jiffy pellets.

Sowing is a mechanized operation. Mechanized sowing involves 2 separate seeding heads to allow prills of slow release fertilizer to be placed in the cavities along with the seeds (Figure 10).

Culturing and seedling transport are also mechanized. Greenhouses are built with additional doors at the ends to allow pallets to be pushed out these doors and moved by equipment. Pallets are placed outside in holding areas for continued growth. Shadehouses are used to condition crops moved outside during the heat of summer, with products such as Chic-o-pee used during the conditioning.

Figure 9. "Kentucky" trailer for hauling seedlings.

Figure 10—Container seed drill with double heads for addition of slow release fertilizer to cells.

Two methods of overwintering are used at the nursery: 1) trays can be placed directly on the ground in holding areas (approximately 50 ft [15 m] wide) cut into the woods—this allows for snow cover during the winter months; and 2) trays may be placed on the ground in the greenhouse—pallets are then placed over the crop and the plastic cover is removed from the greenhouse.

JD Irving, Ltd

JD Irving, Ltd, operates a large industrial nursery in New Brunswick, growing 32 million seedlings per year (all in Multipots). It is a highly mechanized operation, with large machinery for almost all tasks. The average greenhouse is 300 ft by 85 ft by 35 ft high (91 m by 26 m by 11.5 m). Large machinery is used to place crops into the greenhouses. During the growing season, energy curtains are drawn and night break lighting is used in the greenhouses.

The thinning/transplanting operation is one of the few procedures where human hands actually contact the seedlings.

Transport of seedlings to holding areas is done with specialized machines (Figure 11). Frost protection in these holding areas is entirely automated, with curtains used to cover the crops when necessary (Figure 12).

For overwintering, the crop is removed from pallets and placed on the ground. Snow cover is used for overwinter protection. If natural snow cover is not available, snowmaking machines are available (Figure 13).

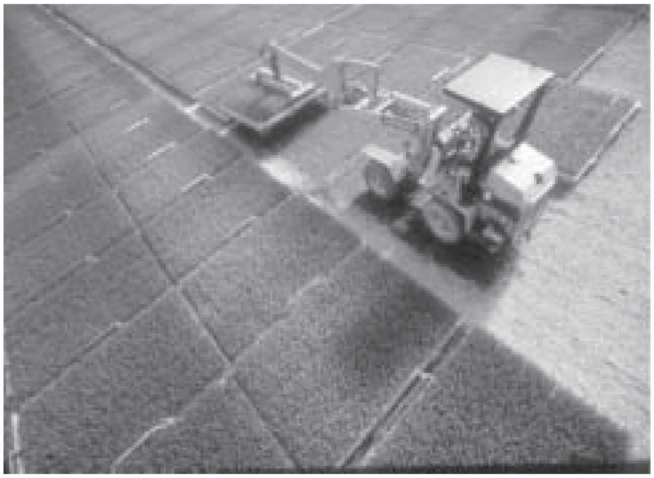

Figure 11—Transport of the crop to holding area.

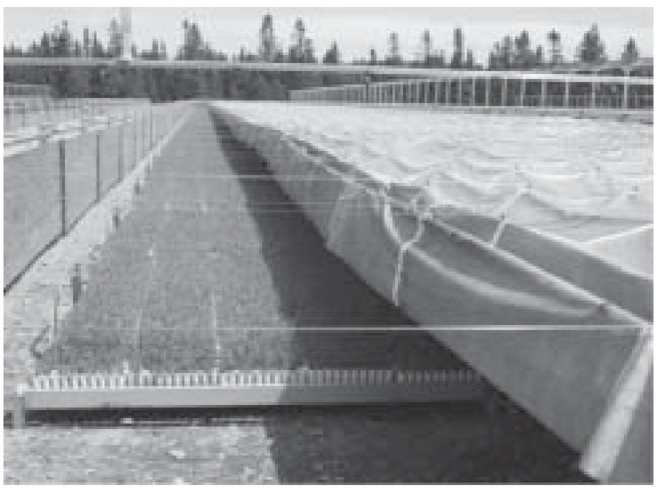

Figure 12—Automatic frost protection system.

Figure 13—Snowmaking equipment for overwintering seedlings.

Tractor trailer units are used to move seedlings to the planting sites. The containers remain on pallets for shipment to these sites. The driver can do all the loading and unloading, with no other crew required.

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Seedling Storage and Handling in Western Canada

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Abstract: Seedling storage and handling techniques are similar across western Canada. Understanding seedling physiology permits management of the prestorage phase and assists in preparing seedlings for storage. Careful handling and packaging, appropriate storage conditions and management, as well as careful thawing and subsequent storage are essential to seedling vigour once outplanted. Outplanting seedlings while frozen has been investigated with favourable results. This new technique is seen as a new way to improve seedling survival and performance.

Keywords: seedling handling, seedling storage, outplanting frozen seedlings

Introduction

Seedling storage and handling are similar in their operations and concerns across western Canada. However, a wide array of issues must be considered based on a great number of nurseries spread across a large and diverse landmass with an equally diverse forest community. In this paper I will attempt to present an overview of the current handling and storage practices across western Canada, and trace the concepts and operational steps followed in handling and storage of seedlings. I will conclude with a report on the research work we are doing on an alternative to thawing seedlings after storage by outplanting the seedlings while still frozen.

State of Seedling Storage in Western Canada

Western Canada is comprised of the provinces of British Columbia, Alberta, Saskatchewan, and Manitoba as well as the Yukon and Northwest Territories. These provinces/territories represent a productive forest land area of 121.4 million ha (~300 million ac) (Lowe and others 1996). In 2002, approximately 291 million seedlings were outplanted on forest land (Table 1) (Canadian Council of Forest Ministers 2003).

Efforts to restore forests to lands denuded by logging, pests, and/or fire have demanded the development of a large forest nursery industry (Table 1). These nurseries were initially established by the provincial governments, but are now largely in the private sector. Nursery production, although initially bareroot, is now overwhelmingly container focused. The container system of choice in western Canada is the Styrofoam container production system initially developed by the BC and Canadian Forest Services.

Most outplanting in western Canada occurs in the spring. As spring arrives across the west at quite different times depending on geographic location and elevation, almost all seedlings are overwintered in frozen storage. This practice permits the availability of seedlings that have been thawed just prior to outplanting. These seedlings have not yet flushed, and are thus in a physiologically appropriate condition to withstand the stress of outplanting and to commence growth. In some locations, such as Manitoba, snow caches are used in conjunction with cold storage. Caches are developed in February and populated with seedlings from frozen storage for local availability once spring arrives in the area.

Storage Preparation and Seedling Storage

A number of planning steps are necessary prior to seedling storage. We are fortunate to be dealing with conifers in that these plants are cold adapted and capable of handling frozen conditions for months at a time. To be able to successfully handle and

Table 1—Number of nurseries and seedlings planted in western Canada (2002).

Province/Territory	British Columbia	Alberta	Saskatchewan	Manitoba	Yukon and NT
Nurseries by Province	30	12	3	1	0
Seedlings planted (million)	205.5	53.0	15.7	16.0	0.8

store seedlings over winter, a good understanding of physiology is necessary (Ritchie and Landis 2003). As conifers move through their annual growth cycles, they respond to a number of triggers that prepare them for winter. Plant processes move from growth to frost hardiness and dormancy. Some of the external changes during this period include cessation of new foliage extension and stem elongation, budset and development, stem lignification, and, finally, cessation of root growth. Internally, cuticle walls in the foliage are thickening, developing waxes on foliage surfaces, translocating soluble sugars, and moving water from cells to the intercellular spaces. Knowledge of these processes and their roles in overwintering allows the nursery manager to induce dormancy and prepare seedlings for storage. Development of dormancy and cold hardiness can be hastened by manipulation of nutrition, by use of short day treatments to trigger budset, and by gradual exposure to lower temperatures.

Across western Canada, nurseries use a testing procedure to determine if seedlings are physiologically ready for lifting, packaging, and cold storage. A "storability" test for this condition was developed by Simpson, Binder, and l'Hirondelle of the BC Ministry of Forests, Research Branch, to determine whether seedlings are sufficiently hardened to withstand the 6 or more months of cold storage (Simpson 1990). The storability test takes samples of seedlings from various geographic locations and elevations of origin and freezes these plants in a controlled freezer to a predetermined temperature threshold (–18 °C [0 °F]). Plants are then assessed for damage to the foliage or cambium. Current testing utilizes the measurement of variable fluorescence to determine if tissue damage has occurred. This gives us results up to 6 days earlier than visual observation.

Some nurseries also track indices such as chilling hours to aid in the determination of appropriate lifting dates. The storability test, however, tests seedling samples directly. This incorporates the response of the plant to the environment and thus has been our preferred method, and has proven a reliable predictor of poststorage health and vigour.

To be able to carry our seedlings through cold storage, especially the nonfrozen periods of this storage, we pay attention to the presence or potential of storage mould. Each crop is assessed prior to packaging to determine if there is a risk of storage mould development. The density of the crops, the fall weather conditions, and the susceptibility of certain species, western redcedar for example, are all taken into consideration (Figure 1). Managers may space crops in the nursery to aid in air circulation and thus lower humidity in order to make it more difficult for *Botrytis* spp. to establish. As a last resort, a fungicide spray may be applied prior to storage to protect the susceptible foliage from mould.

Once the seedlings have reached a physiological condition acceptable for storage, the lifting and packaging can begin.

Figure 1—To prevent storage mould, as illustrated on these western redcedar seedlings, a prelift risk assessment is required, and a fungicide treatment may be required.

Dormant seedlings can withstand some level of stress during the lifting process, but stress in plant tissues is cumulative. Every part of the lifting and packaging process must be designed and managed in a manner to minimize these stresses (McKay 1997). In addition, it is necessary to keep seedlings cool during this process; some species may start to lose frost hardiness and dormancy if exposed to warmer temperatures.

During packaging, the seedlings are bundled and roots are plastic wrapped in groups of 6 to 25 seedlings, depending on stock type size. Bundles are then packaged by placing seedlings in a plastic bag inside a waxed carton. Some nurseries use a paper bag with an inner, poly-lined layer. The reason for the plastic bag or poly layer is to ensure that seedlings do not desiccate in frozen storage over winter. Care is given to properly close the bags to ensure an adequate vapour barrier around seedlings inside the carton (Figure 2).

The storage facilities used in western Canada are of 2 types (Figure 3). Most storage facilities are buildings designed and built primarily for seedling storage, and most of these units are racked. Racking allows palletized storage of seedling cartons from floor to ceiling in the building and thus a very efficient use of space. Other types of storage units are buildings originally designed to store fruit. These buildings are not palletized and thus are usually limited to stacking the cartons 5 high, as more layers would crush the bottom cartons.

All refrigerated buildings have circulation fans to distribute the cold air and keep the temperature as uniform as possible. The normal freezing temperature for seedling

Figure 2—Packaging considerations. An intact and carefully closed vapour barrier, as supplied by this poly bag, is critical to seedling health in cold storage.

storage ranges from –2 to –5 °C (28 to 23 °F) in the refrigeration room and an inside box temperature of –2 °C.

Freezing of seedlings is done as rapidly as possible to minimize carbohydrate reserve losses and reduce the risk of storage mould development. The process of freezing can be accomplished rapidly by dropping the room temperature to –8 °C (18 °F), or spacing the cartons so all have good exposure to the cold air. If the temperature is dropped rapidly, monitoring the inside carton temperatures is important. Temperatures should not drop below –5 °C to avoid damage to seedling roots.

Monitoring of seedlings in storage is critical. Frequent and repeated checking is necessary to assure that seedlings are actually freezing and remaining so. This allows for quick action if problems occur. The performance of the refrigeration equipment needs to be monitored to ensure it is delivering the proper temperatures and airflow. Temperature needs to be recorded throughout storage to ensure the proper ranges of ideal frozen storage are maintained (Kooistra and Bakker 2002a).

Seedling Thawing

Seedling packaging involves grouping plants into bundles. As root plugs freeze together in these bundles, thawing is required prior to outplanting to facilitate seedling separation. Some of our research also suggests that the seedlings are preconditioned through the thawing process, and thus may develop more rapidly once outplanted (Kooistra and Bakker 2002a).

The process of thawing tends to be rapid, taking place over a 5- to 10-day period at temperatures in the thawing facilities of 5 to 15 °C (41 to 59 °F). Once stock is thawed, it is either shipped to the field for outplanting or placed in cool storage (2 °C [36 °F]) until it can be sent to the field. The temperature and condition of the stock is monitored throughout this

Figure 3—Examples of cold storage.

process to ensure that seedlings do not experience adverse conditions, and to detect if storage mould is developing.

Thawing of seedlings is not without its difficulties and can negatively impact seedling quality. Due to operational logistics, seedlings that may be thawed to meet a certain planting date may not be able to be planted on schedule. When this occurs and seedlings are placed back into cool storage, seedlings will use a portion of their carbohydrate reserves during this period, with negative consequences on subsequent growth (Silim and Guy 1998). If plants have been activated sufficiently due to the thaw, the buds may break in the cartons and flushing may occur. This flush is not light adapted, and plants are now much more susceptible to stress. Survival and performance on the outplanting site will therefore be reduced (Figure 4). The risk of storage mould development also increases. Conversely, if the outplanting date is moved ahead, the seedlings will need to be thawed more rapidly. To accomplish this, higher temperatures in the carton will be experienced during thaw, with resultant loss of carbohydrate reserves to fuel higher respiration rates.

Seedlings sent to the field are also handled with care to reduce stress. Transportation can consist of refrigerated trucks, temperature insulated units on pickup trucks, or short distance transport under reflective tarps. Once in the field, some storage may be provided by spotting and operating highway refrigerated trailers, with daily supplies removed as needed. More commonly, a field cache is created where cartons are placed in a shady cool spot with a reflective tarp suspended above the cache.

If the whole process, from preparation for storage in the nursery through the cold storage and thawing phases to the final handling in the field, goes well, then we have all experienced success in the resultant successfully established and performing plantation.

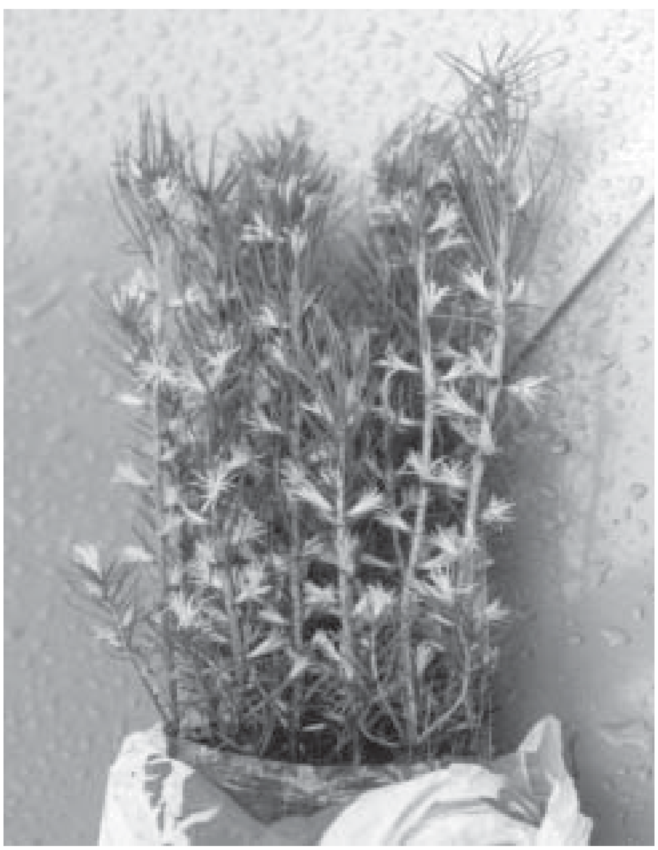

Figure 4—Careful thawing of seedlings and managing of nonfrozen storage are critical to preventing flushing and in minimizing carbohydrate losses, as illustrated in these western larch seedlings.

Another Approach?

The most difficult part of the storage and handling of seedlings from nursery to outplanting site is often seedling thawing and maintenance of seedling quality in the face of operationally changing logistics. In 1998, having determined that it would be possible to package seedlings so separation was possible while still frozen, a study was undertaken to determine if there would be any negative impact on seedlings if outplanted frozen. An example of how these seedlings are wrapped to achieve separation while still frozen can be seen in Figure 5.

The results of the study are reported in Kooistra and Bakker (2002b). I encourage you to read this paper rather than repeat the results here. If you cannot obtain a copy, please contact me at the address above. Briefly, we observed no detrimental effects from outplanting seedlings while frozen. This study was done in a farm field plot. Some argued that it may not be representative of true forest outplanting conditions. Therefore, the study was repeated on 2 forest sites in 2002. The preliminary results to date support the results of the 1998 study. It appears there are few to no detrimental effects to outplanting seedlings while they are still frozen.

In these trials, we measured variable fluorescence before outplanting and for a number of days after outplanting to determine if frozen seedlings were under different stress levels than thawed seedlings. Variable fluorescence measures the fluorescence signature plants emit when the photosynthetic system is stimulated by light. If plants are under stress, variable fluorescence responses (QY) will be lower;

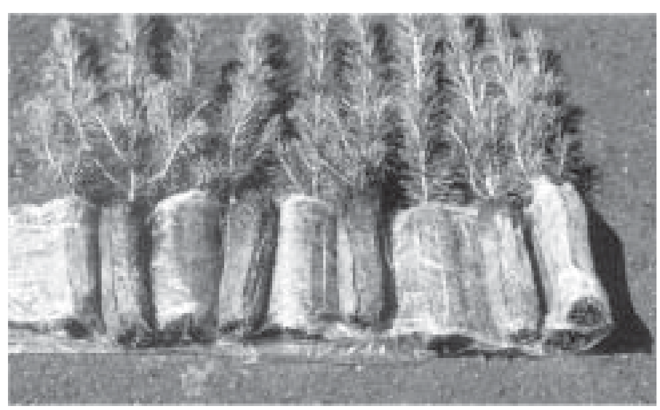

Figure 5—A bundle of “wrapping for planting frozen” seedlings illustrating how the wrap separates each seedling.

this measurement is a good, nondestructive way to determine stress levels in seedlings. It should be noted in the results presented below (Figures 6 and 7), larch (Lw) readings are lower than spruce (Sx) or pine (Pli). This is not due to higher stress levels in Lw, but rather that the measurement taken in this species is of cambial chlorophyll fluorescence as opposed to needle chlorophyll fluorescence in Sx and Pli. The readings for Lw are in the normal range for this type of variable fluorescence measurement.

As in the 1998 study, the 2002 results in Figures 6 and 7 show very little difference among the variable fluorescence readings of either type of seedling. It should be noted that in both studies, the QY readings were slightly higher for thawed seedlings. This is likely due to thawed plants becoming somewhat active by the thawing process, and thus giving slightly higher readings in the first few days. By day 6, there is no difference between thawed and frozen seedlings.

The preliminary data from the end of season measurements are illustrated in Figures 8 and 9. Seedling height (Figure 8) and root collar diameter (RCD) (Figure 9) showed no significant differences between the frozen and thawed treatments across the various trial sites. Initial height and RCD did influence results, as can be seen in the Lw-T results. The differences that were observed in the data so far

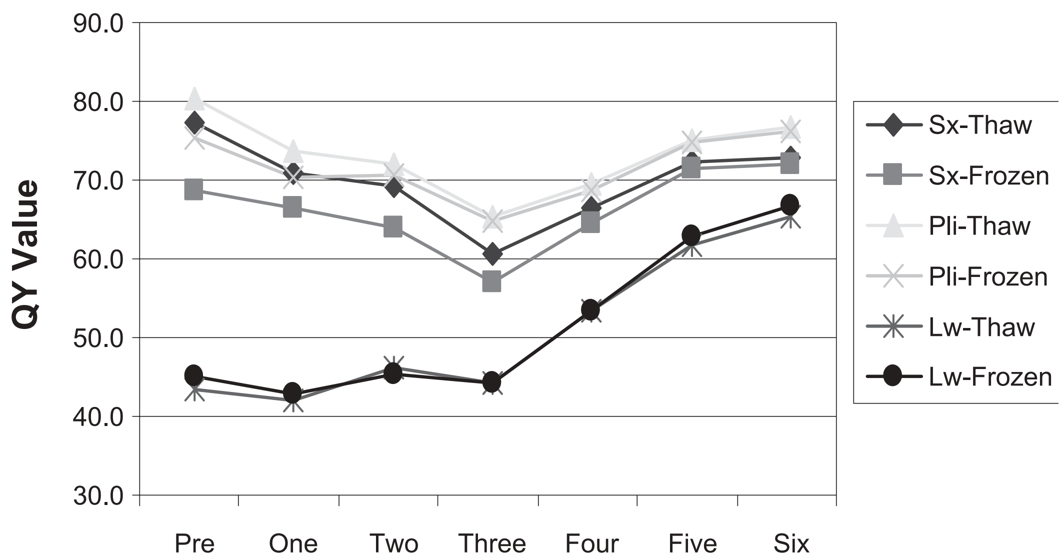

Figure 6—Variable fluorescence for frozen and thawed seedlings in the 2002 Styx Creek outplanting site (Sx = spruce; Pli = pine; Lw = larch).

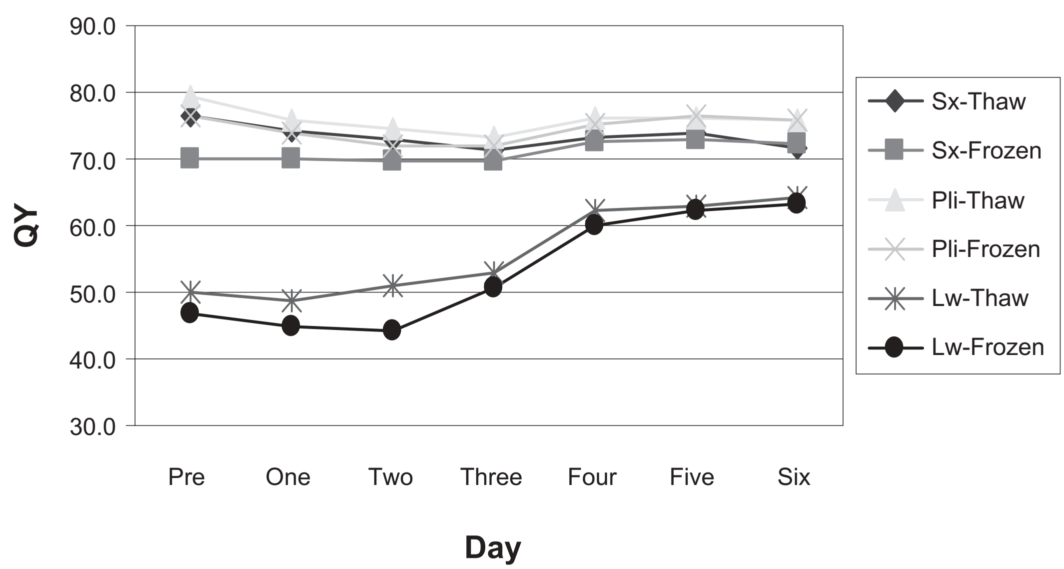

Figure 7—Variable fluorescence for frozen and thawed seedlings in the 2002 South Fork Creek outplanting site.

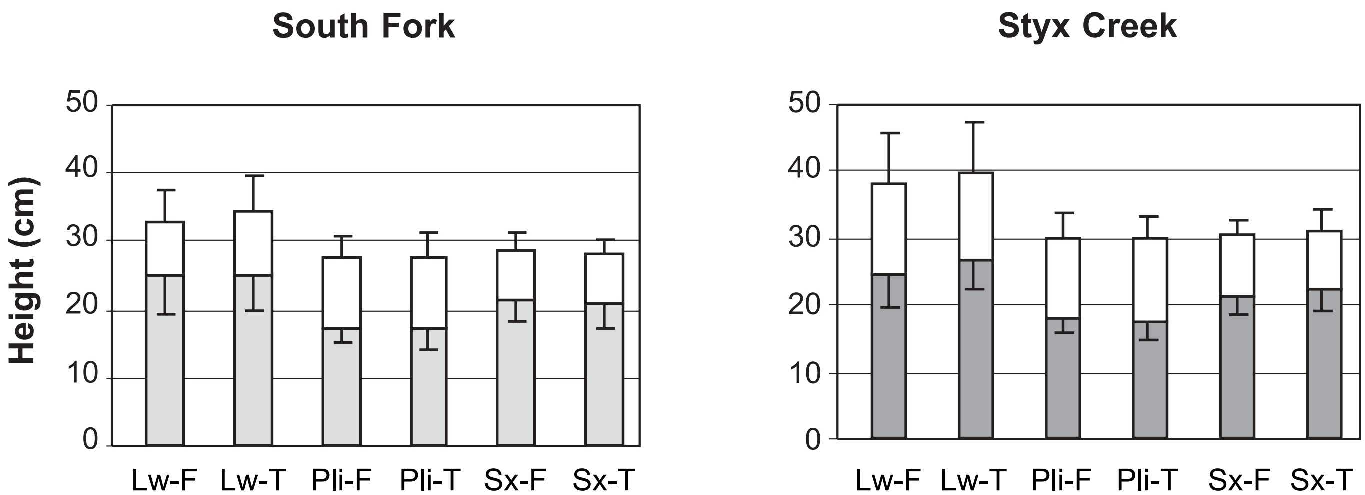

Figure 8—Seedling height for frozen and thawed seedlings at the end of the first growing season in the South Fork Creek and Styx Creek outplanting sites.

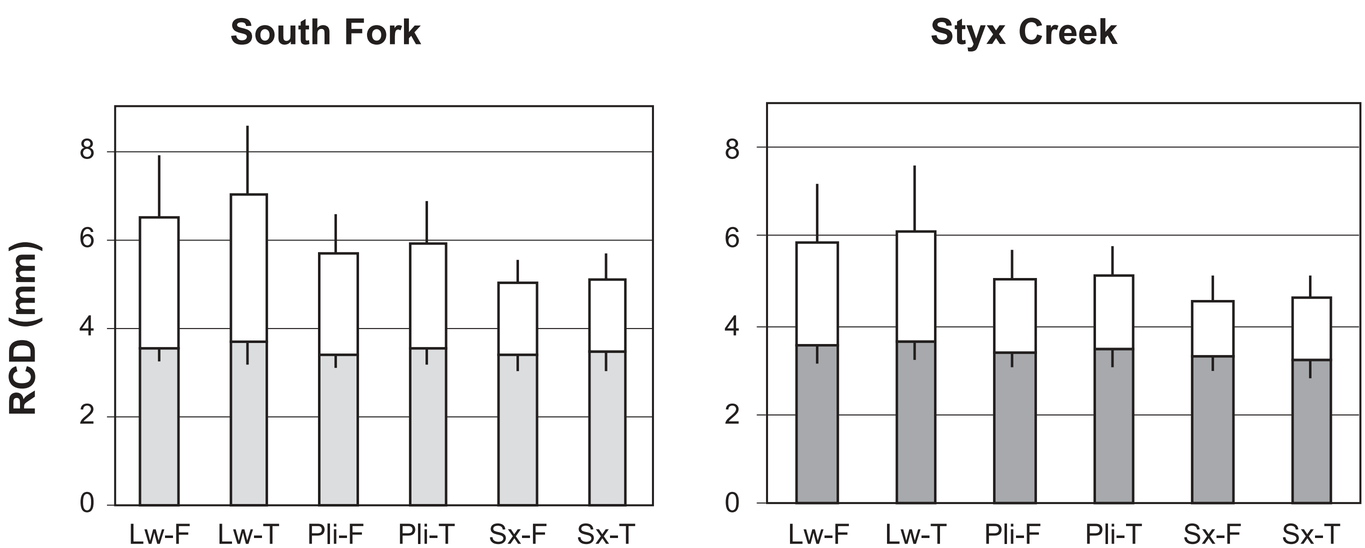

Figure 9—Root collar diameter for frozen and thawed seedlings at the end of the first growing season in the South Fork Creek and Styx Creek outplanting sites.

can be attributed to site differences across the trial plots. It must be stressed this trial is still being analysed and these are preliminary results.

The data from these 2 trials, and the experience from 5 years of increasing operational outplanting of frozen seedlings, indicate that outplanting seedlings while frozen has no significant detrimental effect on survival and performance. It is more likely that this practice may enhance seedling performance through the reduction of stress, while at the same time simplifying spring outplanting logistics. Once operational packaging procedures have been further developed, it is expected that, in western Canada, the practice of outplanting frozen seedlings will continue to expand and become another operational technique employed by those involved in reforestation to ensure and enhance the survival and performance of outplanted seedlings.

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Container Seedling Handling and Storage in the Southeastern States

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Abstract: Most container seedlings grown in the southeastern US are outplanted during winter, although 10 to 20% are outplanted during summer. Longleaf pine accounts for more than 80% of all container seedlings produced. Very little information is published on cold hardiness and storage effects on container-grown southern pines and hardwoods. In general, growers attempt to minimize storage time by coordinating extraction with outplanting, particularly during summer outplanting. Seedlings are hand extracted and placed into wax-coated boxes with slits or holes in the sides, either with or without a plastic liner, and placed into cooler storage. Seedlings for summer outplanting are generally stored at 40 to 70 °F (4 to 21 °C) but usually for a week or less. Seedlings extracted in winter (November through January) are kept at cooler temperatures (35 to 50 °F [2 to 10 °C]), sometimes for as long as 3 months. Research on cold hardiness development would be helpful in understanding proper storage conditions and lengths for southern pines.

Keywords: longleaf pine, slash, loblolly, *Pinus palustris*, *P. elliottii*, *P. taeda*, cold hardiness, hardwoods, research

Introduction

The 3 major reforestation conifer species in the southeastern US are pines: loblolly (*Pinus taeda*), slash (*P. elliottii*), and longleaf (*P. palustris*). For decades these species were only grown as bareroot stock types. Today, all 3 species are grown in containers as well. Despite the fact that container loblolly have been shown to outperform bareroot loblolly on difficult sites (South and Barnett 1986; Barnett and McGilvray 1993), bareroot production still dwarfs container production due to the higher costs of container stock. For longleaf, however, the story is different.

In the 1990s, overall demand for longleaf soared because of federal incentives associated with the Conservation Research Program (Outcalt 2000), peaking at more than 115 million seedlings in 2000 (Figure 1). In the mid 1990s, container production was increasing at 12% or more per year (Hainds 2002), but dramatically increased by more than 2.5 times between 1996 and the peak of production in 2000. In 2000, container production accounted for 70% of all longleaf seedlings grown (Hainds 2003). Demand also surged because, for some landowners, longleaf was considered a more secure investment than the other southern pines because of its fire tolerance, resistance to bark beetles, better growth on sand ridges, and higher value as sawtimber (Hainds 2002). Longleaf stands can be managed under a variety of harvesting techniques (for example, shelterwood, even-aged), and specialty products like pine straw for landscaping markets can increase income (Outcalt 2000).

Container longleaf production surged for several reasons. Container production made more efficient use of seeds in short supply (Barnett and McGilvary 2002). Once produced, container longleaf (Figure 2) are thought to be easier to outplant than bareroot longleaf because their root plugs are more compact and uniform (Hainds 2002; Larson 2002). Container seedlings have a much wider outplanting window, in fact, a year-round outplanting window, but most container longleaf continue to be outplanted from mid-September through March if suitable soil moisture is present. Some operational foresters believe longleaf pine seedlings outplanted between September and November perform better than those outplanted from December through March (Larson 2002), presumably because of the root growth during fall. And most importantly, Boyer (1989) and Barber and Smith (1996) showed that container longleaf survive and grow better on outplanting sites than bareroot stock.

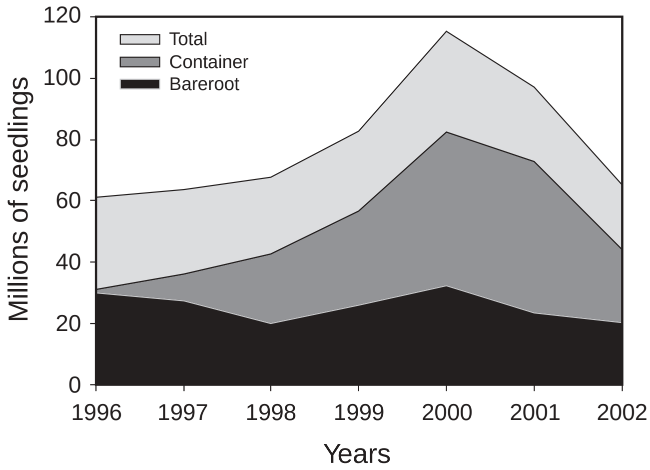

Figure 1—Annual production of bareroot and container longleaf pine seedlings in the southeastern United States from 1996 through 2002 (source Hainds 2003).

Figure 2—Typical longleaf pine container seedling.

Even though millions of container longleaf pine are produced annually, target seedling specifications are still incomplete. Barnett and others (2002) suggest general, interim, morphological specifications without physiological attributes because of the paucity of literature on the latter. Some literature discusses cold storage of bareroot longleaf pine and indicates that seedling morphology and physiology significantly affect field performance after storage (White 1981), but it is unclear how this would correlate with container production. One study with container longleaf reported that roots show very little seasonal variation in cold hardiness, reach maximum hardiness levels in December, and should never be allowed to experience temperatures below 26 °F (–3 °C) to prevent injury (Tinus and others 2002). The need for additional physiological information is borne out by unpublished data supplied by Pickens (2003); he found that seedlings lifted in mid-October and stored up to 8 weeks sometimes performed on outplanting sites as well as seedlings that remain in their containers in the nursery, but other years had 50% less survival.

Although research has yet to be reported, growers are storing container longleaf pine and other species with success. Here we report on some operational practices being conducted in the South, and suggest topics for future research projects that would help clarify the questions surrounding storage of southern pine seedlings.

Current Handling and Storage Practices

Nearly 40 million seedlings are being grown at the 4 nurseries in the southeastern US we surveyed. About 82% of the container seedlings are longleaf pine, followed by 10% loblolly, 6% slash, with 2 nurseries growing about 600,000 "other" seedlings representing 27 species (Table 1; Aiking 2003; McRae 2003; Parkhurst 2003; Pittman 2003). In the South, seedlings are generally outplanted within 2 windows: "summer" which includes April through August (particularly the rainy season months of June through August) and "winter" which is generally November through February, although the trend seems to be for year-round outplanting as long as soil moisture levels permit (McRae 2003; Pittman 2002, 2003). About 80 to 90% of the seedlings are outplanted during winter. The handling and storage of seedlings, however, is much the same regardless of planting season. All of the nurseries attempt to minimize storage by extracting and shipping seedlings to customers in increments equal to what the customers can plant within a week.

Typically, seedlings are irrigated to field capacity prior to extracting from the containers. One nursery applies MilStop, a potassium bicarbonate-based, broad spectrum foliar fungicide with a minimal restricted entry interval (BioWorks Inc, Geneva, New York) to protect against disease during storage (Aiking 2003). Once foliage is dry, containers may or may not be sent through a plug-loosening machine, but all seedlings

Table 1—Annual container seedling production by species at four nurseries in the southeastern United States.

Nursery	Container seedlings produced (millions)			
	Longleaf pine	Loblolly pine	Slash pine	Other[a]
American Tree Seedling, Georgia	10	1	1	
Andrews Nursery, Division of Forestry, State of Florida	4			
Claridge State Forest Seedling Nursery, Division of Forest Resources, State of North Carolina	3	0.1	0.5[b]	
International Forest Company, Georgia	15	3	1.5	0.1
Total	32	4.1	2.5	0.6

[a]Includes: *Aesculus flava* (yellow buckeye); *Carya illinoinensus* (pecan); *Cercis canadensis* (redbud); *Chamaecyparis thyoides* (Atlantic whitecedar); *Cornus florida* (dogwood); *Diospyros virginiana* (persimmon); *Elaeagnus umbellata* (autumn olive); *Lespedeza bicolor* (lespedeza); *Liriodendron tulipifera* (yellow poplar); *Malus* sp. (crabapple); *Prunus angustifolia* (chickasaw plum); *Prunus* sp. (flatwoods plum); *Quercus acutissima* (sawtooth), *alba* (white), *georgiana* (Georgia), *lyrata* (overcup), *michauxii* (swamp chestnut), *nigra* (water), *pagoda* (cherrybark), *phellos* (willow), *prinoides* (dwarf chinkapin), *rubra* (northern red), *shumardii* (Shumard), *texana* (Texas red [formerly Nuttall]), *velutina* (black), *virginiana* (live); *Taxodium distichum* (bald cypress). Nomenclature follows USDA NRCS (2002).
[b]*Chamaecyparis thyoides* (Atlantic whitecedar).

are extracted by hand (Figure 3). Some nurseries use a plastic liner to retard moisture loss. All of the nurseries use wax-coated cardboard boxes, generally developed for some type of produce, and having slits or holes in the side and top of the box to allow air circulation or light entry (Figure 4). Boxes hold between 125 and 400 seedlings depending on species, container volume, and stock size. During summer extraction, seedlings are stored in onsite coolers or rented refrigerated trucks at 40 to 70 °F (4 to 21 °C) for no more than a week. Storage at cool temperatures reduces transpiration and helps maintain moisture in the root plugs. One nursery ships small quantities (300 to 1,500 seedlings) via United Parcel Service because delivery occurs within 2 or 3 days in the South (McRae 2003).

During winter extraction seedlings are extracted and stored in a similar manner, although storage temperatures are generally lower, 35 to 50 °F (2 to 10 °C). Before extracting in winter, nursery managers would like to see the crop experience some hardening temperatures. One nursery attempts to store seedlings no longer than a month, while other nurseries will store seedlings up to 3 months (Figure 5). McRae (2003) uses this general guideline for storage duration: For conifers harvested in September and October, maximum storage length is generally a week or less. By November, seedlings can be held 1 to 2 weeks, and by January seedlings can be held for 2 or 3 months, although loblolly buds may begin to elongate and whiten with longer storage durations.

Hardwoods (“other” species listed in Table 1) are limited to winter outplanting and are generally handled and stored the same way. Although harvesting usually waits until they drop their leaves, it is not always necessary (McRae 2003). Short storage durations also limit disease progression.

Research Needs

Barnett and others (2002), in proposing interim specifications for longleaf pine seedlings, indicate that those guidelines require updating based on evaluating seedling performance over a wide range of morphological and physiological characteristics. Indeed, it would be useful to growers to have information on the interactions between various cultural practices and resulting seedling quality, in terms of both morphological and physiological attributes. For example, optimum foliar nitrogen, or even the range of suitable nitrogen concentrations, is still unknown. We see a need to document the influence of growing seedlings at lower irrigation frequencies to improve water use efficiency and hasten development of cold hardiness in late summer. Answering these

Figure 3—Seedlings are extracted by hand.

Figure 4—Seedlings are place into wax-coated boxes for storage and shipment. Boxes are generally designed for produce and have slits or holes for ventilation and hold between 125 and 400 seedlings.

Figure 5—Once extracted, seedlings can be held for short periods in refrigerated storage until planting.

types of questions should lead to enhanced seedling quality. And, quantifying physiological and morphological characteristics and how they interact during various storage conditions and lengths would be helpful for determining when and for how long seedlings could be stored. Ideally, this type of research would follow seedlings all the way to the outplanting site.

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General Overview of Nutrition for Field and Container Crops

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Keywords: macronutrients, micronutrients, nutrient deficiency, essential nutrients

Introduction

Plants require 17 different essential elements for growth. These 17 essential elements include carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), potassium (K), sulfur (S), calcium (Ca), magnesium (Mg), boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), and zinc (Zn).

These 17 essential elements (also called nutrients) are often split into 3 groups (Figure 1). The first group is the macronutrients that plants can obtain from water and/or air: carbon (C), hydrogen (H), and oxygen (O). The soil does not need to provide these nutrients; thus C, H, and O fertilizers are not marketed for agronomic, horticultural, or home and garden use.

The other 14 essential elements are split into the remaining 2 groups: soil-derived macronutrients and soil-derived micronutrients. This split is based on the actual amount of nutrient required by the plant for adequate growth. The soil-derived macronutrients are nitrogen (N), phosphorus (P), potassium (K), sulfur (S), calcium (Ca), and magnesium (Mg). The soil-derived micronutrients are boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), and zinc (Zn).

Soil-Derived Macronutrients

The 6 soil-derived macronutrients are present in plants at relatively high concentrations, normally exceeding 0.1% of a plant's total dry weight. This translates into a minimum need of 20 lb of each macronutrient per acre each year (22.5 kg/ha/yr).

Nitrogen

Plants require large amounts of N for adequate growth. Plants take up N from the soil as NH_4^+ (ammonium) or NO_3^- (nitrate) (Table 1). A typical plant contains 1.5% N on a dry weight basis; this can range from 0.5% (woody plant) to up to 5.0% (legume).

Nitrogen is a component of amino acids that link together to form proteins in plants. Nitrogen is also a component of protoplasts and enzymes (Table 2). Once in the plant, N is mobile; it can move from older plant tissue to new tissue. Consequently, if N is deficient in plants, the older leaves often turn yellow-green or yellow first. As the deficiency progresses, the entire plant will be yellow.

The major source of N in soils is organic matter (Table 3). Nitrogen is the nutrient generally most limiting in agronomic, horticultural, and home and garden situations in the Pacific Northwest.

Phosphorus

A typical plant contains 0.2% P on a dry weight basis (Table 1); however, depending on the plant species this value can range from 0.1 to 0.5%. Plants take up P as an anion (negative charge): $H_2PO_4^-$, HPO_4^{2-}, or PO_4^{3-}. The actual form of the anion taken up by plants is dependent on soil pH.

Phosphorus is mobile within plants and can travel from old plant tissue to new plant tissue on demand (Table 2). Plants deficient in P are hard to visually diagnose, as deficiency symptoms are not commonly seen. A P-deficient plant is likely to be dark green but have stunted growth. Phosphorus is essential for adenosine diphosphate (ADP), adenosine monophosphate (AMP), and basal metabolism in plants.

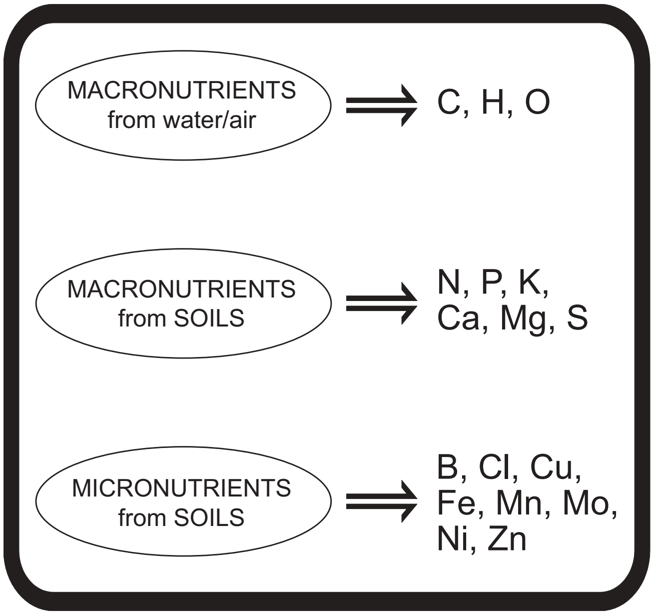

Figure 1—There are 17 essential plant nutrients required for plant growth.

Phosphorus deficiencies in soils can be diagnosed with a soil test. Phosphorus availability is related to soil pH. In general, soils with pH values between 5.5 and 6.8 have adequate levels of plant available P. However, P availability is much lower in soils with pH values below 5.5 or above 6.8 (Table 3).

Potassium

Plants typically contain 1.0% K on a dry weight basis (Table 1). This value can range from 0.5 to 5.0% depending on the plant species. Potassium is held by the clays in soils and is taken up as K^+ by plants.

Potassium is mobile in plants (Table 2). Potassium deficiencies can be diagnosed by looking at the older plant tissue. Deficiencies appear along the outer margins of older leaves as streaks or spots of yellow (mild deficiencies) or brown (severe deficiencies). Potassium plays several roles in plants. It is important for water and energy relationships and has been linked to improved cold hardiness.

Soils in the Pacific Northwest generally contain adequate amounts of potassium for plant growth (Table 3). Potassium problems are isolated to soils where alfalfa and potatoes have been grown for several decades.

Sulfur

Plants take up S from the soil as SO_4^{2-} (sulfate) (Table 1). Because the plant available form of S is negatively charged, it can be leached out of plant root zones with excess precipitation or excess watering. A typical plant contains 0.1% S on a dry weight basis, but this can range from 0.05 to 0.5%.

Sulfur, like N, is a component of some amino acids that link together to form proteins in plants. Sulfur is also a component of protoplasts and enzymes (Table 2). Once in the plant, S has only fair mobility; the new plant tissue will first show a sulfur deficiency. Consequently, if S is deficient in plants the new tissue will often turn yellow-green or yellow.

Sulfur is widely deficient in soils in the Pacific Northwest (Table 3). Low levels of soil organic matter or excess watering can result in S deficiencies.

Calcium

A typical plant contains 0.5% Ca on a dry weight basis (Table 1). However, woody plants may contain up to 5.0% Ca. Calcium, taken up by plants as Ca^{2+}, is required for cell division, cell elongation, and cell structure (Table 2). Since Ca is not mobile in plants, Ca-deficiency symptoms appear at the growing tip of the plant.

Soils in the Pacific Northwest contain plenty of Ca (Table 3). Consequently, Ca deficiencies in plants under agronomic,

Table 1—Uptake form and typical plant content of the 14 soil-derived essential nutrients required for plant growth.

Essential nutrient	Uptake form	Plant content: Average	Plant content: Range
		percent	
Nitrogen	NO_3^-, NH_4^+	1.5	0.5 to 5.0
Phosphorus	$H_2PO_4^-$, HPO_4^{2-}, PO_4^{3-}	0.2	0.1 to 0.5
Potassium	K^+	1.0	0.5 to 5.0
Sulfur	SO_4^{2-}	0.1	0.05 to 0.5
Calcium	Ca^{2+}	0.5	0.5 to 5.0
Magnesium	Mg^{2+}	0.2	0.1 to 1.0
		ppm	
Boron	H_3BO_3, $H_2BO_3^-$, HBO_3^{2-}	20	2 to 100
Chlorine	Cl^-	100	80 to 10,000
Copper	Cu^{2+}	6	2 to 20
Iron	Fe^{2+}	100	50 to 1,000
Manganese	Mn^{2+}	50	20 to 200
Molybdenum	MoO_4^{2-}	0.1	0.05 to 10
Nickel	Ni^+	<<< 0.001	?
Zinc	Zn^{2+}	20	10 to 100

Table 2—Function and mobility within plant tissue of the 14 soil-derived essential nutrients required for plant growth.

Essential nutrient	Mobility in plant	Function in plant
Nitrogen	Good	Proteins, protoplasts, enzymes
Phosphorus	Good	ATP, ADP, basal metabolism
Potassium	Good	Water relations, energy relations, cold hardiness
Sulfur	Fair/poor	Proteins, protoplasts, enzymes
Calcium	Very poor	Cell structure, cell division, cell elongation
Magnesium	Good	Chlorophyll, enzymes
Boron	Very poor	Sugar translocation, cell development, growth regulators
Chlorine	Good	Photosynthesis
Copper	Poor	Enzyme activation
Iron	Poor	Chlorophyll synthesis, metabolism, enzyme activation
Manganese	Poor	Hill reaction-photosystem II, enzyme activation
Molybdenum	Poor	Nitrogen fixation, nitrogen use
Nickel	Unknown	Iron metabolism

Table 3—Typical soil content and most likely associated problems in the Pacific Northwest for the 14 soil-derived essential nutrients required for plant growth.

Essential nutrient	Typical soil content	Likely problems
Nitrogen	1 to 2% organic matter	Widespread
Phosphorus	1 to 4 ppm (Morgan); 4 to 20 ppm (Olson)	Widespread; low pH (<5.5); high pH (>6.5)
Potassium	>100 ppm	Isolated to potatoes, alfalfa
Sulfur	<10 ppm	Widespread
Calcium	Plenty	No problems
Magnesium	Plenty	No problems
Boron	0.1 to 0.7 ppm	Low organic matter soils, high ppt
Chlorine	Plenty	No problems
Copper	1.0 to 3.0 ppm	Soils with over 8% organic matter
Iron	Plenty in low pH soils	High soil pH values (>7.5)
Manganese	Plenty	Very isolated
Molybdenum	No soil test	When growing legumes in soils with pH values <5.4
Nickel	No soil test	No problems
Zinc	0.3 to 2.0 ppm	Where topsoil has been removed

horticultural, or lawn and garden situations have never been observed in the region.

Magnesium

Plants typically contain 0.2% Mg on a dry weight basis (Table 1). This value can range from 0.1 to 1.0% depending on the plant species. Magnesium is held by the clays and organic matter in soils and is taken up as Mg^{2+} by plants.

Magnesium is mobile in plants (Table 2). Magnesium deficiencies can be diagnosed by looking at the older plant tissue. Deficiencies appear as interveinal chlorosis in the older plant leaves; the veins of the leaves stay dark green but the areas between the veins appear yellow-green, yellow, or white in color. Magnesium is a component of chlorophyll in plants.

Most soils in the Pacific Northwest contain adequate amounts of Mg for plant growth (Table 3). Magnesium problems are isolated to soils with pH values below 5.2.

Soil-Derived Micronutrients

The 8 soil-derived micronutrients are present in plants at relatively low concentrations, often just a few parts per million (ppm) of a plant's total dry weight. These values translate into a need of 0.5 to 2 lb of most micronutrients/ac/yr (0.6 to 2.3 kg/ha/yr).

Boron

Plants require about 20 ppm of B (Table 1). Boron is taken up by plants as an uncharged molecule (H_3BO_3) or as an anion ($H_2BO_3^-$, HBO_3^{2-}). Since the plant-available form of B is not positively charged, it is leachable in soils and is often lost from the plant root zone by over-irrigation or excess precipitation.

In plants, B promotes the translocation of sugars, cell development, and is believed to be important for growth regulators (Table 2). Boron is not mobile in plants. Consequently, B-deficiency symptoms most likely appear on the growing tip of the plant. In B-deficient plants the growing tip is often deformed.

Soils that contain less than 1.5% organic matter or are over-irrigated tend to be deficient in B (Table 3). Boron deficiencies are common on agronomic crops, fruit trees, and in urban gardens. For additional information on B, see University of Idaho CIS 1085, *Boron in Idaho*, available at URL: http://info.ag.uidaho.edu/catalog/catalog.html.

Chlorine

Plants generally contain about 100 ppm of chlorine (Table 1). Chlorine is taken up as Cl^- by plants and is required for photosynthesis (Table 2). Chlorine is plentiful in soils in the Pacific Northwest. Consequently, Cl deficiencies in plants will not be encountered.

Copper

Copper is taken up as Cu^{2+} by plants (Table 1). Concentrations of Cu in plants average 6 ppm, but can range from 2 to 20 ppm. Copper is a component of cytochromes in plants and needed for enzyme activation. Copper is not mobile in plants, causing deficiencies to first appear in the youngest plant tissue (Table 2).

Most soils contain adequate levels of Cu for plant growth (Table 3). Copper problems are most likely in soils that contain more than 8% organic matter, which constitutes only about 1% of the soils in the Pacific Northwest. For additional information on Cu, see University of Idaho CIS 682, *Copper in Idaho*, available at URL: http://info.ag.uidaho.edu/catalog/catalog.html.

Iron

Plants take up iron (Fe) as Fe^{2+} (Table 1). A typical plant contains 100 ppm of Fe; this can range from 50 to 1000 ppm depending on plant species. Iron is needed by plants for chlorophyll synthesis, metabolic processes, and enzyme activation (Table 2). Iron is not mobile in plants, resulting in Fe deficiencies first appearing on younger leaves. The characteristic deficiency symptom is interveinal chlorosis in the younger leaves.

In general, there is plenty of plant-available Fe in acid and neutral pH soils (Table 3). In the Pacific Northwest, Fe deficiencies are often observed in fruit trees, on golf course greens, and in ornamental plantings in urban areas. Iron deficiencies should be corrected with foliar sprays.

Manganese

Manganese is taken up as Mn^{2+} by plants (Table 1). Concentrations of Mn in plants average 50 ppm, but can range from 20 to 200 ppm. Manganese is required in the Hill reaction of photosystem II and is important for enzyme activation. Manganese is not mobile in plants, causing deficiencies to first appear in the youngest plant tissue (Table 2).

Most soils contain adequate levels of Mn for plant growth (Table 3). Manganese deficiencies are not found in acid or neutral pH soils. The few observed Mn deficiencies in Idaho occur on alkaline soils that have high levels of organic matter (greater than 6%).

Molybdenum

Plants take up molybdenum (Mo) as MoO_4^{2-} (Table 1). A typical plant contains only 0.1 ppm of Mo. However, this small amount of Mo allows plants to utilize nitrogen. In addition, legumes require Mo for nitrogen fixation (Table 2).

Molybdenum is not mobile in plants, so deficiency symptoms appear in younger plant tissue first. Molybdenum-deficient plants turn yellow-green to yellow in color. Most Mo deficiencies occur when legumes are grown in soils with pH values less than 5.4. For additional information on Mo, see University of Idaho CIS 1087, *Molybdenum in Idaho*, available at URL: http://info.ag.uidaho.edu/catalog/catalog.html.

Nickel

Nickel (Ni) was added to the essential element list in 1991. Plants require less than one part per billion Ni. Nickel is believed to be important in iron metabolism in plants. Because such a small amount of Ni is required by plants, deficiencies have never been observed in the Pacific Northwest.

Zinc

A typical plant contains 20 ppm Zn on a dry weight basis (Table 1). Plants take up zinc as Zn^{2+}. Zinc is required for protein breakdown and in enzyme activation in plants (Table 2). Zinc is not very mobile in plants; consequently deficiency symptoms first appear on the youngest plant tissue. Most soils in the Pacific Northwest contain adequate amounts of Zn (Table 3). However, Zn deficiencies do occur in soils where the topsoil or organic matter has been removed. For additional information about Zn, see University of Idaho CIS 1088, *Zinc in Idaho*, available at URL: http://info.ag.uidaho.edu/catalog/catalog.html.

Summary

Nitrogen, phosphorus, and sulfur are the macronutrients that will most likely limit the growth of field and container crops. Under certain conditions, boron and iron micronutrient nutritional problems may also be encountered.

Soil and Water Management Plans for Bareroot Nurseries

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Abstract: A soil management plan should include historical and current environmental assets and liabilities, including geomorphic origin and past land use. Each nursery has its own unique soil, water, and climatic conditions, and these should be considered. Primarily, a plan should represent a team effort by the soils specialist and the nursery personnel who work the ground and raise the seedlings. With contributions from all those involved, the plan can address operational functions such as tillage, irrigation, cultivation, fertilization, trafficability, and harvesting. The success of a management plan as a useful tool depends upon the commitment of all concerned.

Keywords: soil nutrient status, foliar nutrient status, cultural practices, soil amendments, cover crops, soil texture

Introduction

In preparation of the *Forest Nursery Manual: Production of Bareroot Seedlings* (Duryea and Landis 1984), a questionnaire was sent to 21 Northwest bareroot nurseries. The response indicated that the 6 most important considerations (in site selection characteristics) were: 1) soil workability and drainage; 2) soil texture; 3) water supply; 4) land cost; 5) climate; and 6) soil depth (Morby 1984). It is evident that nursery managers consider soil and water characteristics as major concerns.

Additional, and more specific, guidance comes from Warkentin (1984), who has offered a list of physical characteristics desired in a nursery soil. These characteristics are optimal proportions of air and water in soil pores after natural drainage, rapid drainage of excess water from the soil, adequate infiltration rate for rainfall or irrigation water, high resistance to compaction, low shear strength for easy harvest of seedlings, low adhesion of soil to seedling roots, and absence of frost heaving, erosion, and soil splash onto seedlings. These features provide the starting points for gathering basic information necessary to make the ultimate interpretations for the needs of the nursery staff.

It can't be overly emphasized that the majority of soil and water problems (including chemical or nutrient imbalances) in bareroot production result from changes in the physical conditions. Therefore, both the existing and the potential status (resulting from cultural activities) must be recognized or anticipated by the soils specialist as well as the nursery staff.

Of utmost importance is the concept that a soil and water plan must be visualized as a management tool, not merely as an inventory of existing conditions. This requires a working knowledge of all the cultural activities that routinely take place at the nursery. Most soils specialists are not familiar with these operations, such as the number of necessary tractor trips, what implements are involved during specific moisture conditions, and the irrigation schedules. It is important that the nursery staff become involved in educating the soils specialists as to all the events included in raising the seedling stock. A bareroot nursery operation is undoubtedly one of the most intensive farming operations existing.

The following discussion on the content and substance of a soil and water management plan is offered to assist the nursery personnel in the development of a working and dynamic product. The soil and water management plan for J Herbert Stone Nursery (USDA Forest Service, Medford, OR) serves as an example.

Plan Introduction

Long-term nursery objectives are recorded in the Management Plan introduction (Boyer 1993). These can be short and simple, but necessarily explicit. For example, objectives might include developing more uniform crops, reducing chemical usage, managing the soils to their best potential, and increasing the quality of water leaving the nursery, including reduction of sediments and nitrates.

The introduction may also include past land use, climatic factors, soil origin, and source of irrigation water. Historical information, such as past studies regarding soil physical and chemical properties and water quality analyses, could be presented.

Soil/Foliar Nutrient Status

The "Nutrient Regime" is a logical place to begin the plan's second part. A discussion of macronutrients and micronutrients and past laboratory analyses of both soil and foliar samples is appropriate to this section. Target levels for the individual species to be grown, as well as guidelines for different stages of seedling development, could be defined. As an example, every species and cultural group requires a different level of nitrogen. Some generalities that have been used in the past include: 1) high rates of nitrogen are used for 1+0 for shipping, high elevation species and species to be grown "large"; 2) moderate rates of nitrogen are applied to low elevation species; and 3) low rates of nitrogen are significant to transplants and sugar pine.

A discussion of fertilizers and soil amendments is also useful when it provides data regarding acid-producing products or sources of sulfur and/or micronutrients. A table of Standard Treatments, including fertilizer types, rates, and schedules of applications might be included in this section. The annual fertilizer schedule can be presented, along with the quantity and type of fertilizer to be applied at specific times during the season, starting with the planting dates. These treatments can be specific according to the various cultural groups, such as ponderosa pine for shipping at 1+0, ponderosa pine to be grown for 2+0, or ponderosa pine and Jeffery pine grown for 2+0 of medium height and caliper, and so on. This information can be useful in ordering annual purchases. It also gives the soils specialist an insight as to what and how much is being applied and the number of applications.

Any past research pertaining to growth and cultural practices should be included, such as the report on root and shoot growth of Douglas-fir and ponderosa pine in bareroot nursery seedbeds at J Herbert Stone Nursery (Riley 1992). This report was especially useful, as it recognizes important stages in the life of the seedling and the timing of cultural activities to maximize the potential growth.

One of the most significant contributions from the Stone Nursery staff was to provide an example of the Pre- and Post-Soil Treatments. This included field location, species to be grown, and target height and caliper. All of the scheduled cultural activities involved were also listed, including sowing density, wrenching, mulching, fertilizer banding, and irrigation at various growth stages. Pest management and root pruning were also mentioned. This schedule provides guidance to the nursery personnel performing the tasks. In addition, the nursery culturist, or soils specialist, developing the fertilizer regime will find it useful in fine-tuning fertilizer applications to obtain objectives with the least amount of effort. It also gives a clear view of all the activities involved and their specific points in time.

Soil Amendments

Discussion of amendments (organic and inorganic) and cover crops is included in Section 3 of the Management Plan (Boyer 1993). (See Rose and others 1995 for further information.)

The JH Stone Nursery Soil and Water Plan also provides sawdust prescription guidelines, including timing of application, storage areas, sampling, sawdust size distribution, application rates, supplemental additions of nitrogen, and inspection of delivered product.

Laboratory Analysis

Section 4 includes lab analysis and comments regarding irrigation water, surface waters, sediment traps, ground water (including subsurface drainage system water quality), and studies dealing with nitrate and other chemical leaching.

Nursery Soil and Water Conditions

Section 5 presents the soil and water conditions for the entire nursery and each production field. Maps were prepared to illustrate surface soil color, surface soil textures, particle size analysis (lab tests), abrupt change in soil texture from surface soil, mottling (by depth increments), and water tables (immediate and 24-hour readings). A discussion of trafficability (listing those operations that produce the least to the most compactive effect) and nutrient status trends are also provided. All of these factors are of an "inventory" nature, but are useful in the selection of certain fields for specific species as well as indicating where potential problems might arise, such as subsurface drainage system failures.

One distinct product of the field investigation is the map of particle size distribution. A major concern at this nursery was the location and extent of the fine- and very fine-sized mica fragments. The inferences of this map indicate potential compaction, surface crusting, inhibitors to seedling emergence, infiltration rates for irrigation waters, and adhesion of soil particles to roots during lifting operations.

Other maps, such as soil color, infer differences in organic matter content or presence of coarse (gravel-sized) fragments that may interfere with sowing operations or contain abrasive properties damaging to field implements.

The map indicating abrupt changes in soil textures from surface soil has references to irrigation duration and frequency. It may also infer reduced soil water downward movement, which ultimately raises the potential for compaction, pathogenic activity, or at least, problems in trafficability.

All these observations are the basis for the interpretations that follow. They also represent the elements the nursery staff deem essential to operations. Along with all the past soil and foliar analyses, a list of interpretations for each field is given, which includes germination/survival, soil tilth, practices to maintain organic matter levels, limitations for farm machinery, irrigation, and best use of the land.

There is a large difference between developing field data and providing soil and water interpretations. The nursery staff has an obligation to question any of the interpretations. The rationale should be obvious to the personnel concerned so that there is no misunderstanding or lack of agreement. This is part of the total commitment! If this doesn't occur, the plan will not be useful and will stand the danger of being relegated to a dusty shelf.

Another requirement, particularly if the soil resource specialist is involved in the annual fertilizer recommendations, is that he/she should be present at lifting time. The specialist can then observe whether seedling morphology (height, caliper, and root mass) meet the objectives desired by the nursery. If this is not convenient, then a copy of the cull percentage and/or comments by the staff as to whether the fertilizer regime met or did not meet necessary goals should be provided.

The soils specialist must have the desire to perform to the highest technical standards possible and thoroughly understand all the operations involved in bareroot production. This is a tall order, but necessary for a solid and functional plan. The interpretations must be sound and backed by sufficient rationale. This requires questioning his/her own judgment and either gathering additional supporting data or rejecting the interpretation.

A soil and water management plan that will serve as a dynamic, functioning tool can be accomplished if the individuals, from tractor driver to nursery manager to soils specialist, are willing participants and are committed to mutual objectives.

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Subsurface Banding of Phosphorus, Potassium, and Controlled Release Nitrogen Fertilizers in the 1+0 Year at J Herbert Stone Nursery

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Abstract: At J Herbert Stone Nursery, fertilizer practices have evolved from pre-sow broadcast application of phosphorus (P) and potassium (K) fertilizers to exact placement of these fertilizers in a subsurface band at the same time the seeds are sown. Recent administrative studies at the nursery have shown that banding controlled release nitrogen (N) fertilizers with P and K fertilizers is effective in achieving the same or better seedling responses the first growing season as broadcast application of conventional N fertilizers. Subsurface banding of N, P, and K fertilizers at sowing can reduce soil compaction, decrease nitrate leaching, reduce salt buildup, reduce the potential for early season diseases, and can be less expensive.

Keywords: nitrate leaching, controlled release fertilizers, federal nurseries, bareroot seedlings, soil compaction

Introduction

Maintaining adequate fertility in bareroot nurseries is essential for producing a target seedling for outplanting. This is accomplished through the use of fertilizers that are either applied before sowing or during the active seedling growth phase. There are several methods of fertilizing seedlings, but perhaps the most common method used by bareroot nurseries is to broadcast apply fertilizers on the ground, then incorporate or irrigate them into the soil. This paper looks at an alternative application method being practiced at J Herbert Stone Nursery called subsurface banding. Subsurface banding is an often-overlooked method of applying fertilizers, yet it has many advantages over broadcast application methods including improving plant growth (van den Driesshe 1984). We have found at J Herbert Stone Nursery that this method can: 1) reduce fertilizer use; 2) decrease nitrate leaching; 3) reduce the potential for salt toxicity and early season disease; 4) reduce soil compaction; and 5) lower overall costs.

Past Fertilization Practices

Until the mid 1980s, our nursery broadcast-applied phosphorus (P) and potassium (K) fertilizers prior to sowing by applying each separately with a tractor-drawn fertilizer spreader, then disking them into the soil with a final tractor pass. We used very high rates of P because our soils have a high affinity for fixing P, making it unavailable for root uptake (Boyer 1993).

After seedling emergence, broadcast applications of ammonium nitrate and ammonium sulfate were made at 10- to 14-day intervals. Dry fertilizer was applied over 3 beds (not the paths) using a Barber spreader. Immediately after application, beds were irrigated to dissolve the fertilizer and move it off the foliage and into the soil profile. This began in late May and continued until mid July. Depending on the target specification for the crop, there were up to 5 applications in a season.

Problems Associated With Broadcast Application

The spring months are often wet in southwestern Oregon. Excess moisture, coupled with our slow draining fields, results in the workability of our soils as less than optimum prior to sowing. The use of tractors for applying and disking P and K fertilizers will compact or puddle soils. Mitigating measures, such as deep ripping or subsoiling, have limited success under these conditions. The resulting effects of soil compaction on our crops can be devastating (Figure 1). In the compacted tractor paths created prior to sowing, seedlings have reduced root volumes and are often yellow and stunted. For our nursery, the best management practice is to limit the number of tractor passes over our fields when the soils are susceptible to compaction (Warkentin 1984).

Applying nitrogen (N) fertilizers over the 1+0 crop in the early stages of seedling development is often a risk to seedling health. In the late spring and early summer, the climate at our nursery can turn hot. Average maximum air temperatures by late June exceed 85 °F (29 °C) and are often 10 to 20 °F (6 to 12 °C) hotter at the soil surface. This is a period when seedlings are small, succulent, and most susceptible to salt toxicity and damping-off diseases associated with broadcast application of N fertilizers.

The higher surface salts associated with broadcasting N fertilizers can create moisture stress conditions in seedlings, especially where water distribution is uneven or durations of irrigation are not long enough to move fertilizers into the soil profile. In 1984, we experienced salt toxicity across our fields. That year the irrigation schedule for the 1+0 crop was a series of short bursts of water to the cool the surface of the soil when temperatures reached 90 °F (32 °C). With the high surface evaporation rates associated with the warm temperatures, fertilizer salts came to the soil surface through capillary action and were deposited there. Under these conditions the surface salt levels far exceeded the acceptable levels for seedling growth, and many seedlings either died or had very low vigor. We looked for solutions to this problem and found that seedbed mulching and periodic, deep irrigations would move concentrated salts away from the soil surface and eliminate this problem. Nevertheless, we still occasionally experience this problem in some fields from year to year.

Figure 1—Lines of lighter colored seedlings caused by compaction associated with broadcast application P and K fertilizers prior to sowing.

High levels of surface N also increase the potential for damping-off diseases. At our nursery, damping-off occurs up until mid-July and often increases after we broadcast apply N fertilizers. The treatment is the same as with salt buildup—irrigate until the N and salts have moved sufficiently into the soil profile.

The high rates of N used in broadcast fertilization, plus the need for longer irrigations to move salts and N into the soil profile, increase the potential for nitrate leaching into the ground water. Nitrate leaching is a long-term concern to Stone Nursery because we are located in an area where our neighbors depend on well water for domestic use. The area surrounding the nursery is becoming more and more residential with time.

Subsurface Banding: An Alternative Method of Fertilizer Application

It should come as no surprise that our nursery started looking for alternatives to broadcasting P, K, and N fertilizers. In the mid 1980s, we began to apply P and K fertilizers with a bander at the same time we sowed seeds. We purchased a fertilizer bander from a local agricultural equipment dealer and then made a few modifications. The fertilizer bander came with a hopper that holds up to 900 lb (400 kg) fertilizer, a fertilizer metering system, and delivery tubes attached to knives that place the fertilizer at the desired soil depth. Over time we replaced the knives with rolling coulters from a Love-Öyjørd seed drill so there would be less soil disturbance. We also attached a hydraulically controlled metering system to ensure accurate fertilizer rates. Then we mounted the bander to the front of a Love-Öyjørd seed drill to obtain an exact placement of concentrated fertilizer in relation to the seeds (Figure 2). We adjusted the bander to place fertilizer 3 to 4 in (7.5 to 10 cm) deep and exactly between each seed row (Figure 3). The offset of fertilizer precisely between seed rows is important since it eliminates the potential of direct contact of fertilizer salts to the sensitive, developing root system.

We have banded P and K fertilizers for over 15 years with good success and minor problems. Recently we considered the possibilities of subsurface banding controlled release N fertilizers and, in 2000 and 2001, we installed separate nursery fertilizer trials to test the effects of different rates of banded controlled release N fertilizers on seedling growth. The results, as will be discussed below, showed equal growth responses in one trial and significantly greater growth in another and gave us the assurance to try this operationally at the nursery.

Benefits of Subsurface Banding

The advantages of subsurface application of fertilizers in the 1+0 year at Stone Nursery are many and are summarized below.

Figure 2—Bander consists of fertilizer hopper (A), hydraulically controlled, chain-driven fertilizer meter (B), drop tubes (C), and coulters (D) that place fertilizer in the soil.

Less Trips, Less Soil Compaction

By subsurface banding P and K fertilizers, we have significantly reduced the amount of soil compaction by eliminating 3 tractor trips prior to sowing. In turn this has also freed up tractors for other important spring work around the nursery.

Less Fertilizer Needed

Phosphorus and Potassium Fertilizer—When our nursery switched to banding P and K fertilizers, we reduced the amount of P and K fertilizers applied per acre by at least a third. Seedling growth and nutrient levels were not affected by the reduced rates. P and K fertilizers can be reduced because concentrated banded fertilizer has less soil contact. Since P and, to a lesser extent, K are fixed in the soil, less soil contact means more nutrients are available to the seedling around the banded fertilizer zone (Havlin and others 1999).

Nitrogen Fertilizer—In recent years, fertilizer trials at Stone Nursery have shown that much smaller amounts of N in a controlled release fertilizer form are needed to achieve the same or better seedling growth responses when these fertilizers are subsurface banded. In 2000, we compared a polymer-encapsulated sulfur coated urea (35N:0P_2O_5:0K_2O:18S with a 5 to 6 month longevity) at 2 rates (50 and 100 lb N/ac [57 and 113 kg N/ha) against our standard broadcast application of 141 lb N/ac (160 kg N/ha) (as ammonium nitrate and ammonium sulfate). Polymer-encapsulated sulfur coated urea treatments were banded at sowing, while our standard N fertilizer was broadcast applied at approximately 10-day intervals between June and

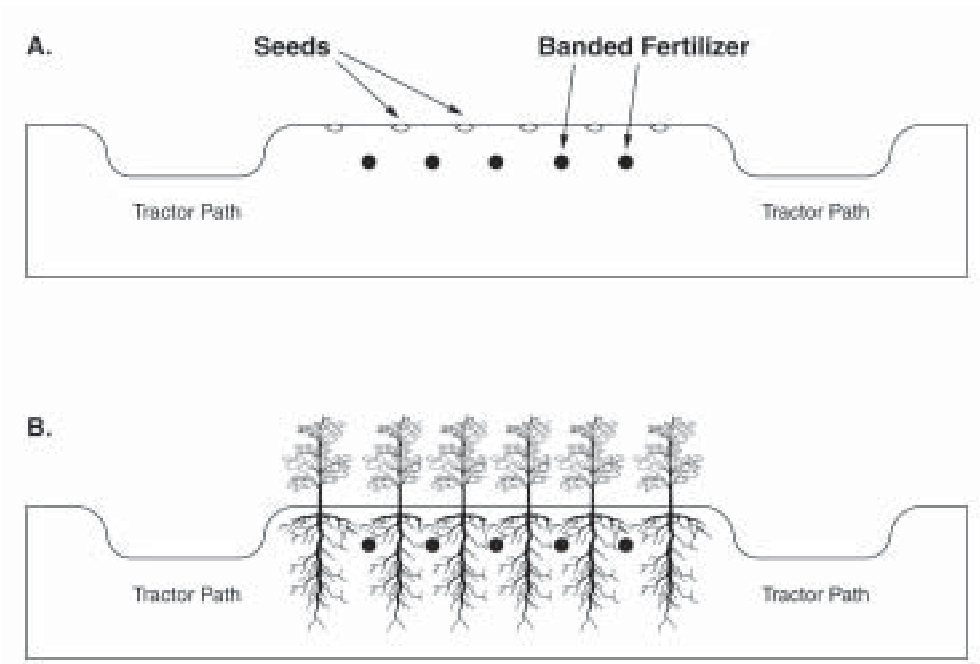

Figure 3—Fertilizers are placed between seed rows and at a depth of 3 to 4 in (7.5 to 10 cm) in the soil during sowing (A). Fertilizers are accessed by the root systems as seedlings develop (B).

early July. The treatments were replicated 4 times in a randomized block design on 1+0 ship ponderosa pine seedlings.

Seedlings were lifted the following winter and measured for height, stem diameter, root area, and shoot area. Results showed that seedlings from the controlled release fertilizer treatments at 50 and 100 lb/ac (57 and 113 kg/ha) rates were significantly taller (P = 0.10) than the standard nursery fertilization treatment (Table 1). Stem diameters were also significantly larger for the 100 lb/ac controlled release fertilizer treatment. The percent of seedlings with heights less than 6 in (15 cm) (considered a minimum height for some clients) were 41% for seedlings grown under standard fertilizer regimes as compared to 33% for the 50 lb/ac and 28% for the 100 lb/ac treatments. Foliar nutrient analysis showed very similar N values for all treatments. A similar controlled release banding trial installed the following year showed no difference between treatments.

Less Potential for Salt Toxicity and Disease

Newly emergent seedlings should have less exposure to salts and high N concentrations with banded controlled release fertilizers because it is placed between the seeds and below the surface of the soil (Figure 3). Even if irrigation patterns or scheduling were conducive to bringing salts to the soil surface, the salts would still have to move 3 to 4 in (8 to 10 cm) upward through the soil. Under these conditions, the concentrated salts would accumulate between the seedling rows and not around the seedling stem. Since controlled release N fertilizers are placed at a depth of 3 to 4 in (8 to 10 cm), N levels near the stem of the seedling are not as high as would be found under a broadcast fertilizer regime. Lower N levels should reduce the susceptibility of seedlings to damping-off diseases.

Continuous N Feeding

Controlled release fertilizers become available as soil temperatures increase. Because of the release nature of these fertilizers, N availability more closely coincides with the growth of the seedling. Instead of large inputs of N to the soil in a feast and famine schedule every 10 to 14 days with broadcast N fertilizers, controlled release fertilizers meter N continually during the growing season as soil temperatures increase. In contrast to broadcast applications that begin 6 weeks after seedling emergence, subsurface-banded fertilizers are available to the seedling soon after seedling emergence.

Less Costs, More Flexibility

Using controlled release fertilizers in bareroot operations seems uneconomical at first glance because of the higher product costs. Yet because 4 to 5 fertilizer applications are eliminated with banding and the amount of controlled release fertilizer purchased is less, the total banding fertilization program can be far less expensive. At Stone Nursery in 2003, these savings have offset the extra cost of purchasing controlled release fertilizer (Figure 4). The reduced amount of P and K fertilizers, the elimination of 3 tractor trips to apply and incorporate these fertilizers, and the switch from broadcast to banding N, P, and K fertilizers can result in a costs savings approaching 50%. Perhaps as important as savings, we have found that our equipment and personnel are freed up to do other critical work during that time of year.

Less Nitrate Leaching

A primary goal for changing fertilizer systems at Stone Nursery was to reduce the amount of nitrates potentially leaching into the ground water. The high solubility of conventional N fertilizers used in broadcast fertilization, the frequent fertilizer applications, and the longer irrigations increase the potential for nitrate leaching. By applying controlled release fertilizer, we are reducing the rate of N fertilizer use by at least a third, which correspondingly reduces the potential for nitrate leaching by a third.

Disadvantages of Subsurface Banded Fertilizers

Early experiences in banding P and K fertilizers impressed upon us the importance of placing fertilizers exactly between the seed rows. In the first years of banding, fertilizers were placed immediately below the seed row. We noticed in those years that some seedlings were either stunted or stressed in the early part of the growing season. Upon excavating these seedlings, we found that the developing taproots were hitting the banded fertilizer at 4 in (10 cm) and stopping because of the presence of high fertilizer salts.

Table 1—Results from an administrative study comparing banded controlled release nitrogen fertilizers with broadcast applied fertilizers on a 1+0 ship ponderosa pine seedlot.

		Stem diameter	Height	Seedlings culled <10 cm	Seedlings culled <12.5 cm	Seedlings culled <15 cm	Foliar nutrients N	Foliar nutrients P	Foliar nutrients K
		mm	*cm*	*percent*					
Standard broadcast	141 lb N/ac (160 kg N/ha)	6.5[a]	15.2[a]	9[a]	23[a]	41[a]	2.42	0.24	0.78
Banded controlled release	50 lb N/ac (57 kg N/ha)	6.5[a]	16.7[b]	5[a]	14[a]	33[b]	2.31	.23	.88
Banded controlled release	100 lb N/ac (113 kg N/ac)	6.6[b]	17.1[b]	4[a]	11[a]	28[ab]	2.46	.23	.88

Letter differences denote significant treatment differences at the 95% confidence level for percent seedlings culled and stem diameter and 90 percent confidence level for height.

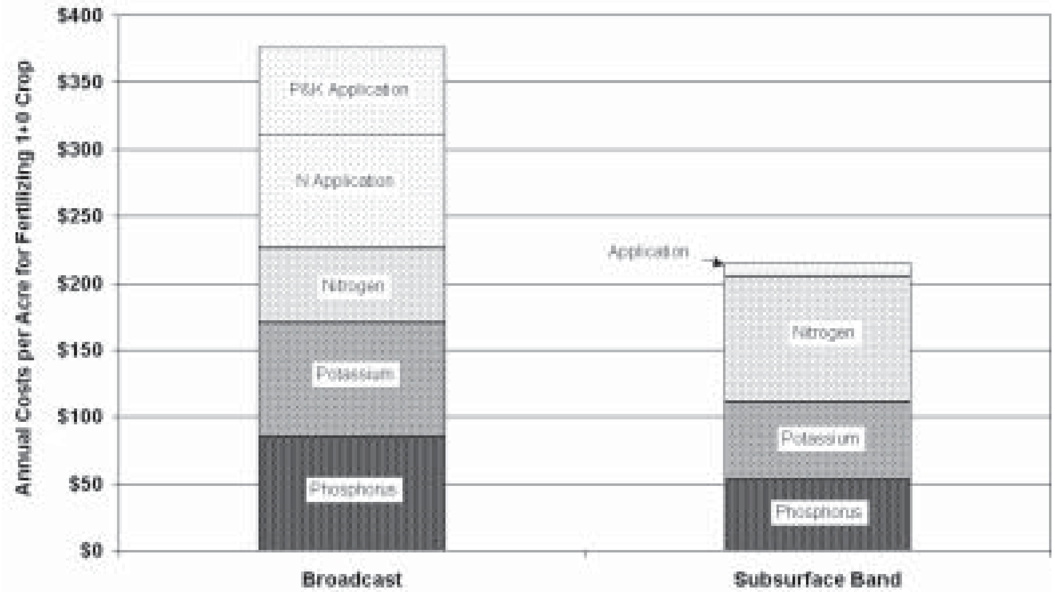

Figure 4—Cost comparison of current fertilizer practices where all fertilizer is subsurface banded with past practices of broadcast applying fertilizers in the 1+0 year.

While this did not kill seedlings, it significantly reduced first-year growth. This problem was easily corrected by placing the bander coulters between the seed rows.

The presence of N in the late summer can affect seedling hardening. If controlled release fertilizers are still supplying N at this time of year, shutting down seedling growth could be difficult. Given the hot summer climate of our region, we don't anticipate this will be a problem since seedling hardening can be induced by limiting the amount of irrigation or by wrenching the seedbed. If it does become a problem, we will reduce the amount of controlled release fertilizer that we use or switch to a fertilizer with a shorter release period.

Using controlled release fertilizers requires that we become more aware of the seedling nutrient status and growth patterns. If a crop shows reduced growth rates or signs of nutrient deficiencies in the early season, we will have to supplement the controlled release fertilizers with one or more broadcast applications of conventional N fertilizers. The use of banded controlled release fertilizers will require more crop monitoring during the early stages of seedling development.

Summary

At J Herbert Stone Nursery we have learned that subsurface banding P, K, and controlled release N fertilizers in the first growing season is a cost effective alternative to broadcast application methods. Subsurface banding can reduce soil compaction, reduce fertilizer use, decrease nitrate leaching, decrease potential for salt toxicity and early season diseases, and be less expensive. Fertilizer banding equipment is available through local agricultural equipment suppliers and with some modification can be adapted to bareroot sowing equipment.

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Fertilizer Application: Balancing Precision, Efficacy, and Cost

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Abstract: Fertilizer prescriptions and application methods are unique for each nursery. The choice in application method must balance the accuracy of the application versus the cost and speed of the application. The major types of application equipment are compared.

Keywords: nutrient application, fertilizer application equipment, sprayer

Introduction

To continually grow high quality seedlings on the same nursery site, nutrients must be added to replace nutrients lost when seedlings are harvested. There are many factors that impact how effective the nutrient application will be for seedling growth. These factors include when and where the fertilizer is applied and availability of the various nutrients to the seedling. Nutrient availability will depend on both soil properties and the ability of the seedling to extract the nutrients from the soil. The emphasis in this paper will be on the physical means of applying nutrients to seedlings in a bareroot nursery using timely and economical procedures.

Basic Considerations

The need for a fertilizer application will probably be based on soil nutrient analysis, tissue analysis, stock performance, and historical trends. Fertilizer prescriptions are unique to each nursery (van den Driessche 1984). Once the nutrients to be applied and the type of fertilizer to use have been selected, options for application equipment and placement of the fertilizer are limited. The choice of application equipment will be just as unique to the nursery and the fertilizer prescription.

Nutrients can generally be selected in a soluble or insoluble form. The soluble form of some nutrients, like phosphorus, can be significantly more expensive than the insoluble form. In the bareroot nursery, these nutrients are primarily applied as dry material. Some fertilizers will combine a couple of nutrients in a single product. For example, ammonium phosphate supplies nitrogen and phosphorus; sulfate of potash magnesia supplies potassium, magnesium, and sulfur. Where multiple nutrients are needed that cannot be provided by a single fertilizer, either multiple applications or use of a blended fertilizer is necessary. The blended fertilizers are generally cheaper, and the single application is more efficient. There are drawbacks to this method that will be discussed under application methods.

Availability of the nutrients to the seedlings depends on the type of fertilizer, soil properties, nutrient properties, and fertilizer placement. The common forms of nitrogen fertilizer are readily leachable; use of sulfur-coated urea and other slow release forms of nitrogen can extend the time that the nitrogen will remain in the soil. Phosphorus is not readily leachable but chemically combines with other soil material. Over time, it changes from readily available phosphates to slower and slower available forms (Buckman and Brady 1969).

Fertilizer placement will determine how much and how readily the nutrients are available to the seedlings. The fertilizer can be spread over the entire area, including the area of the tractor paths. Alternatively, the material can be applied only to the area of the beds. After application, the material can be left on the surface to be washed into the soil with irrigation, or incorporated into the root zone. Banded placement, where fertilizer is drilled into the soil below or beside the seedlings, combines into one operation the distribution and incorporation of the fertilizer. Once again, there is no single correct answer.

Application Options

Once the fertilizer to apply and the desired location of the application have been selected, there are a variety of application equipment options. The chosen option will have a large impact on the efficiency and efficacy of the application and the cost of the fertilizer used. This must be balanced with the cost of the application equipment. The following types of equipment will be compared: rotary spin spreader, air-blast boom spreader, auger drop box spreader, liquid sprayer, and banding equipment. Uses for the various types of spreaders and advantages and disadvantages are summarized in Table 1.

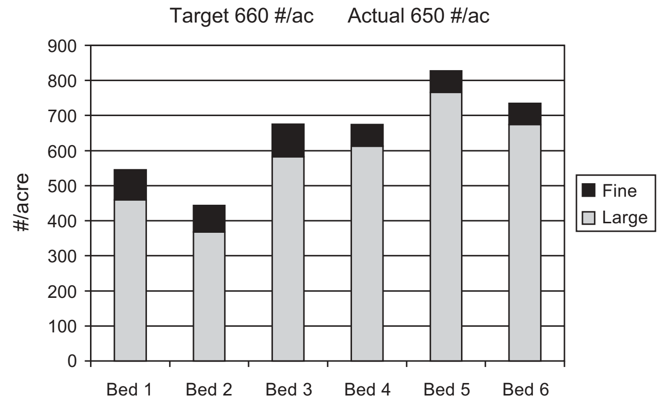

Figure 1—Fertilizer distribution with the Lely Rotary Spreader.

Rotary Spin Spreader

The rotary spin spreader consists of a hopper for the fertilizer that is gravity-fed through a metering gate that is used for calibration. One or more rotating disks below the metering gate distribute the fertilizer. Typically, it spreads fertilizer in a 30- or 40-ft (9- or 12-m) width. This application method is not very efficient. With a small hopper that holds 700 lb (320 kg), you may only spread about 1 ac (0.4 ha) before you need to return to refill. If you are using bagged fertilizer in 50- or 80-lb (23- or 36-kg) bags, this can raise some concern for safety when bags must be emptied into the hopper that is at shoulder height. The safety concern can be eliminated by having fertilizer delivered from your fertilizer dealer in a tender with a power auger.

The distribution from a rotary spin spreader is not very accurate. The distribution on an acre basis is typically within ±5%, but the distribution across the working width can be ±35% or more. If you are using a blended fertilizer as compared with a single product, you can get some gravity separation between materials. Figure 1 shows the results from catch pan samples using a Lely Rotary Spreader. On a per acre basis, the application was 98% of plan. Fine particles were 92% of plan; the large particle sizes were 99% of plan. The difference between the highest rate per bed and the lowest rate per bed was almost 2:1. This type of spreader is generally used for preplant broadcast applications where 42% of the fertilizer would be placed in tractor paths that will not be used to grow seedlings. It can also be used for growing season applications.

Air-Blast Boom Spreader

Most of the issues with the rotary spin spreader for preplant applications can be corrected by using an air-blast boom spreader. These spreaders consist of a larger hopper holding several tons of fertilizer. The fertilizer is metered and then distributed along a boom with many drop nozzles using air pressure. These spreaders come with wide floatation tires to distribute the heavy load. The air-blast boom spreader provides a more even distribution of fertilizer, and is not subject to the separation of particles sizes. These spreaders still fertilize the entire area, so a significant amount of fertilizer remains in the future tractor paths. The large floatation tires limit use of the air-blast boom spreader to preplant applications only. These spreaders are expensive. Because of the limited use they would receive, most nurseries would use the services of a commercial spreader to make these applications.

Auger Drop Box Spreader

For growing season applications of dry fertilizer without fertilization of the tractor paths, a drop box spreader can be used. A drop spreader uses a variable worm gear to evenly distribute the fertilizer along the base of the hopper. The fertilizer then falls by gravity onto the bed through small

Table 1—Application equipment uses and efficiency.

	Rotary spreader	Air-blast boom	Auger drop box	Banding spreader	Sprayer
Uses					
Pre-plant (before beds)	Yes	Yes	Possible	No	Possible
Pre-plant (after beds)	Yes	No	Yes	Yes	Yes
Growing season	Yes	No	Yes	No	Yes
Tractor paths fertilized	Yes	Yes	No	No	No
Type of fertilizer	Dry	Dry	Dry	Any	Liquid
Speed	Fair	Excellent	Poor	Poor	Excellent
Accuracy	OK	Good	Good	OK	Excellent
Uniformity	Poor	OK	OK	Good	Excellent
Calibration ease	Difficult	Easy	Average	Average	Excellent
Cost of equipment	<$1000	>$50000	<$1000	<$5000	<$5000

openings on the base. This type of spreader is more accurate than the rotary spin applicator, but it covers a much smaller area on each pass. A typical unit only covers a single bed; with a gang of spreaders, 2 or more beds can be fertilized on a single pass. The hoppers are generally small and require frequent refilling. The distribution is good regardless of particle distribution. The small openings can become plugged if there are impurities in the fertilizer or large particle sizes. It is difficult to see when this happens from the tractor. Until the hole clears itself, or is cleaned, the reduced amount of fertilizer distributed from the plugged hole results in the appearance of yellow striping in the crop 2 or 3 weeks after application.

Liquid Sprayer

A sprayer can also be used to apply any soluble fertilizer onto seedling beds very accurately and efficiently. A stock solution is diluted in the spray tank and then sprayed on the crop. This method can also be used for foliar feeding. Typically, however, the material is washed off the foliage into the soil for root uptake. The more concentrated the solution, the more important it is to get irrigation started to prevent burning of the foliage. On sensitive species or hot dry days, water needs to be started at or before the time spraying begins. On cooler, cloudy days or with less sensitive species, irrigations should start in less than 1 hour from when spraying begins. The use of computer controlled spray equipment allows for changes in application rates as necessary for species or areas requiring more or less nutrients. These changes can be made without stopping or changing the calibration.

Fertilizer dealers can often provide solutions of several basic blends. The solution is delivered in a tank truck and pumped into your storage tank. Fertilizers purchased in solution are generally less expensive per pound of nutrient than when purchased dry (Yeager 1999). Storage tanks should be plastic with PVC fittings to prevent corrosion and rust. A small transfer pump can be used to pump the stock solution into a measuring container. The measuring container can be a graduated plastic container of 100 gal (380 l) or more with a drain valve at the bottom. The measured solution can be lifted by forklift to drain into the spray tank. This system is easy and safe to use. Goggles should be worn when working with the concentrated solution to prevent splashing in the eyes. There is very little physical labor involved with this method.

If solutions cannot be delivered in your area, you can mix your own. The system can be very simple or more elaborate depending on how much it will be used. A mixing tank of sufficient volume to dissolve the desired chemical is necessary. A table of solubility of fertilizer materials can be found *The Farm Chemical Handbook*. Water is added to the mixing tank followed by the dry fertilizer with some type of agitation. Agitation can be mechanical, jet agitation using a circulating pump, or a pneumatic agitator using air pressure. After the fertilizer is dissolved, it can be transferred to the spray tank with a pump, or gravity fed using the forklift method described above. Use of a platform to stand on and a scissor lift to raise the fertilizer bags to tank height makes the operation safer. Once again, use of goggles when mixing the solution is necessary to prevent splashing in the eyes.

All of the application methods discussed can be used to distribute fertilizers to the seedlings with certain limitations. The commercial air-blast spreader can only be used as a preplant application system. The sprayer is limited to fertilizers that are readily soluble. When we apply fertilizer, we want to get the material on in a timely manner; there are great differences between the application methods in how long it will take to make the application. The choice in application method must balance the accuracy of the application compared with the speed of the application. Use of a drop box spreader could take 2 weeks to cover the nursery. By using a rotary spin applicator, the job could be done in 2 days. Figure 2 shows the comparison between the different application methods.

Other Options

In addition to the standard broadcast methods, other methods for fertilizer application have some applicability. Banding application of fertilizer at the time of sowing is one of these alternatives. For immobile nutrients, like phosphorus, this may be advantageous, although it might not result in an improvement in yield (Murrell 1998). Fertilizer is only placed where it is necessary, and if it does not slow the sowing operation down, it would be an acceptable practice. Banding is probably not an option with transplant seedlings because of the disruption to the bed that would be necessary to place fertilizer below the transplants.

Use of the sprayer for foliar feeding of nutrients is not widely practiced in bareroot nurseries (van den Driessche 1984). Concentration of nutrients must be kept low to prevent foliage burning; thus frequent applications are necessary. Concentrations would only be about one-tenth of the concentration used when the sprayer is used for broadcast spreading followed by irrigation.

Application of nutrients through the irrigation system is only used in very few bareroot nurseries. The practice known as fertigation is common in the greenhouse; irrigation in the bareroot nursery is not as uniform because of wind and topography, and is subject to runoff. A nursery using a

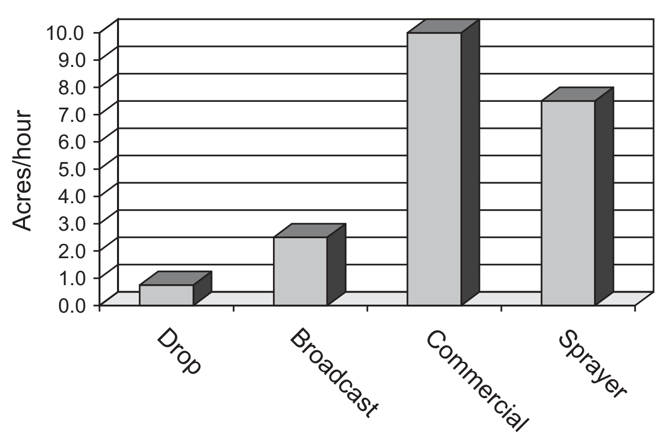

Figure 2—Efficiency of application methods.

center-pivot irrigation system successfully uses this method (Triebwasser and Altsuler 1995).

Conclusions

Each nursery develops its own reliable process for selection of fertilizer and fertilizer equipment to use in growing quality seedlings. This process is based on what has worked in the past and the equipment that is available. In every case, the application method must balance the accuracy of the application versus the cost and speed of the application. There is no single answer that is always best.

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Nutriplug™: The Next Generation

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Abstract: Providing an added or residual fertilizer load in the plugs of forest tree seedlings prior to outplanting has been an objective pursued by nurseries and forestry operators through the years. Pacific Regeneration Technologies (PRT) has been actively researching and developing means to enhance the performance of forest tree seedlings by providing a fertilizer load at the time of outplanting with the development of its Nutriplug™ product. We are currently experimenting with a technology to deliver metered amounts of controlled release fertilizer in the seedling plug at time-of-lift.

Keywords: container seedlings, fertilizer incorporation, controlled release fertilizer

Introduction

Although achieved by various techniques, delivering an added fertilizer load in the plug at time-of-lift serves a common objective—to make nutrients available to the seedling after outplanting. It is hypothesized that, on certain sites, this will result in the reduction of "planting check" and enhance growth in the first few years after outplanting. The following is a brief review of the various techniques serving this objective.

Fertilization at Time of Sowing (FAS)

A controlled release fertilizer (CRF) with a long release span is incorporated into the growing medium via the mixing equipment at the time of sowing. Although some nutrients are released during the crop cycle at the nursery, there is a significant residual effect after outplanting. This concept was used to develop the Nutriplug™ and was the object of several trials. These trials are briefly described in this paper.

Fertilization at Time of Planting (FAP)

Incorporation of a CRF at time-of-planting involves the tree planters placing fertilizer near the seedling root system at outplanting time. Several commercially available products carry the fertilizers in different chemical and physical forms (for example, "teabags" or planting tabs, polymer-coated or IBDU, and so on).

This concept has been the object of numerous field trials in British Columbia over the past 25 years. Some forestry practitioners use it operationally. Results have been inconsistent, although some very positive results have been reported. Adequate soil moisture seems to be a key factor in obtaining a positive growth response.

Nutrient Loading

Nutrient loading involves growing seedlings in the nursery using extremely high fertilizer levels, enabling the uptake of more nutrients than needed (that is, luxury consumption). After outplanting, the seedlings have the capability to relocate some of these excess nutrients from the older tissues to the new growth. Some forestry practitioners outplant operationally nutrient loaded trees grown by PRT with the Exponta™ regimen. Some studies clearly indicate significantly higher growth of these trees when compared to non-nutrient loaded control seedlings the first year after outplanting.

Brief Overview of the Work and Development Done With Nutriplug™

As previously mentioned, we undertook to develop a value-added product that would enhance field performance and provide a cost effective alternative to fertilization at time-of-planting. The results gathered since the early 1990s using the FAS concept have demonstrated some interesting results, and led us to the development of the Fertilization at Time-of-Lift (FAL) concept.

Although the FAS Nutriplug™ has the advantage of being cost effective when compared to FAP techniques, we are still facing some sizable constraints.

Prill Distribution

It has been challenging to achieve a uniform prill distribution from plug to plug using our existing medium mixing equipment in the nursery (Figure 1). This has proven particularly difficult with batch mixers.

Prill Integrity

If the mixing time is too short, the variation in prill distribution increases; if it is too long, we risk damaging the coating of some of the prills, generating high salt levels in the growing medium.

Release

The controlled release mechanism of most fertilizers is generally triggered by temperature or moisture (or a combination of both) (Figure 2). Given the fact that the seedlings are exposed to moist and warm conditions during the nursery cultural cycle, a fair amount of fertilizers are released at the nursery.

Outplanting Trials

With these limitations in mind, PRT has been working on the development of the FAS and FAP Nutriplug™. Several trials have been done through the years; some with very positive results. The following are some excerpts of selected trials.

Spring Outplanted Interior Spruce FAS/FAP—

Locations: The Tahtsa Reach trial was established on 2 cutblocks approximately 100 km (62 mi) SW of Houston, BC (latitude 53°43', longitude 127°58'). Both sites are in the Moist Cold Subzone of the Sub-Boreal Spruce (SBSmc2).

The Whitesail and Nadina trials were established near Houston, BC (approximately 100 km [62 mi] SE of Smithers). Interior spruce was spring outplanted in 1997. The Whitesail site is a low vegetation, dry site. The Nadina West site is a wet site, making it difficult for the planters to identify acceptable microsites. This resulted in a low overall survival.

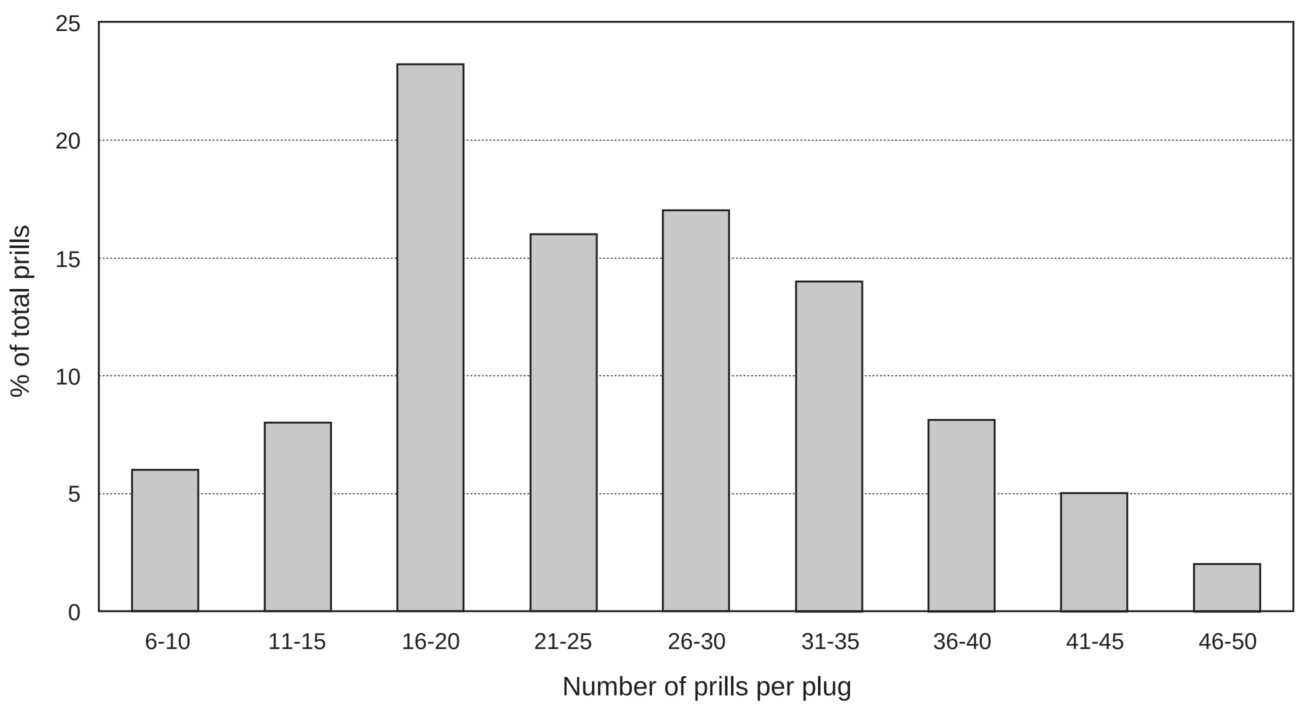

Figure 1—Typical prill distribution from plug to plug for the PRT 99-NT410 prill distribution. Target is 24; average is 25.

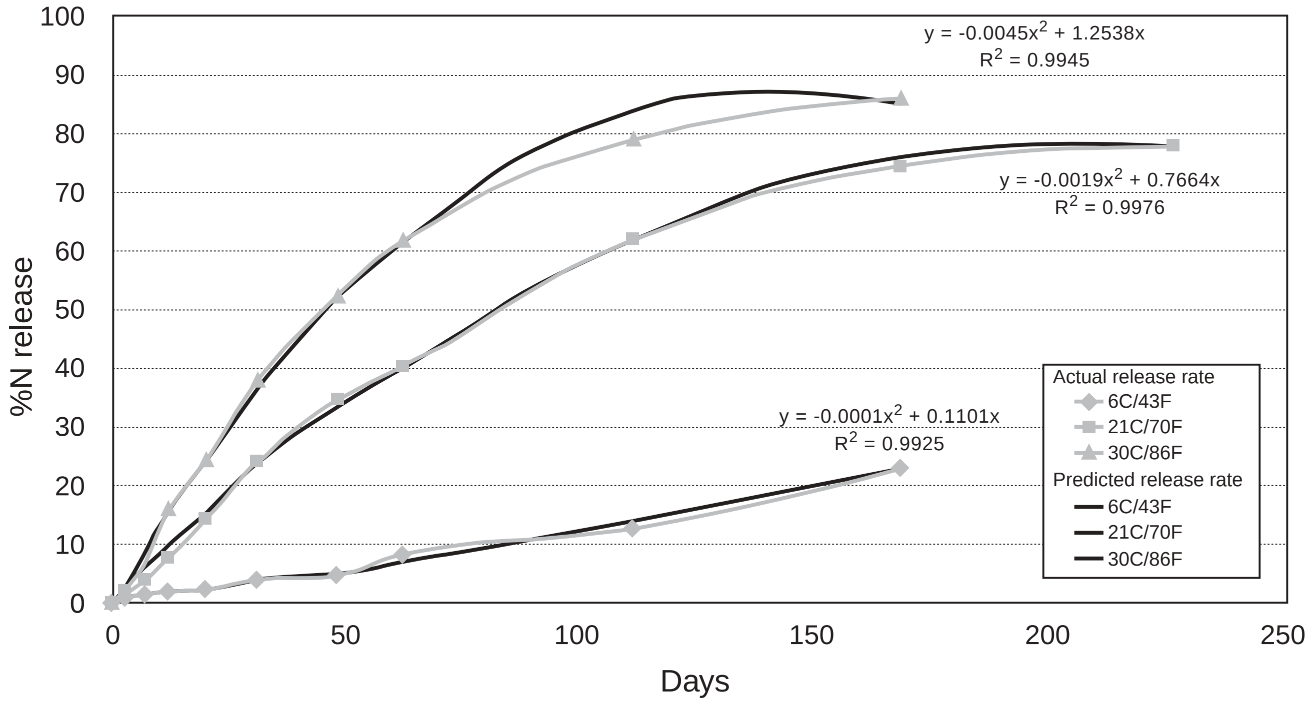

Figure 2—Actual nitrogen-release curve compared to the predicted release rate for the controlled release fertilizer Multicote 18N:6P_2O_5:12K_2O (5- to 6-month formulation) at 3 different temperatures.

Treatments: A commercially available CRF was tested in conjunction with a control and the "tea bag."

1. Control. The control seedlings were those produced under operational culturing procedures.
2. Nutriplug™ FAS. Nutricote 16N:10P_2O_5:10K_2O CRF with a 12-month release formulation (at 25 °C [77 °F] soil temperature) was incorporated into the growing media. Approximately 30% was released while seedlings were still in the nursery.
3. "Tea Bag." Silva-Pak™ 26N:12P_2O_5:6K_2O (10 g [0.35 oz]) polymer-coated urea with a 12-month release formulation (at 21 °C [70 °F] soil temperature) was placed in the planting hole at mid-plug depth approximately 2 cm (0.8 in) from the plug.

Results: Results after 3 years of measurements for the Tahtsa Reach trial are shown in Figure 3. Initial seedling height was significantly greater for the Nutriplug™ treatment at outplanting. However, annual height growth was significantly greater in the "tea bag" treatment following the second and third growing seasons (Figure 3A). Initial diameter measurements were significantly greater in the "tea bag" treatment at outplanting. Annual diameter growth was also significantly greater in this treatment following the second and third growing seasons (Figure 3B).

Results after 5 years of measurements for the Whitesail trial are shown in Figure 4. Initial seedling height was significantly greater for the Nutriplug™ treatment at outplanting. Annual height growth was significantly greater in both the Nutriplug™ and "tea bag" treatments as compared

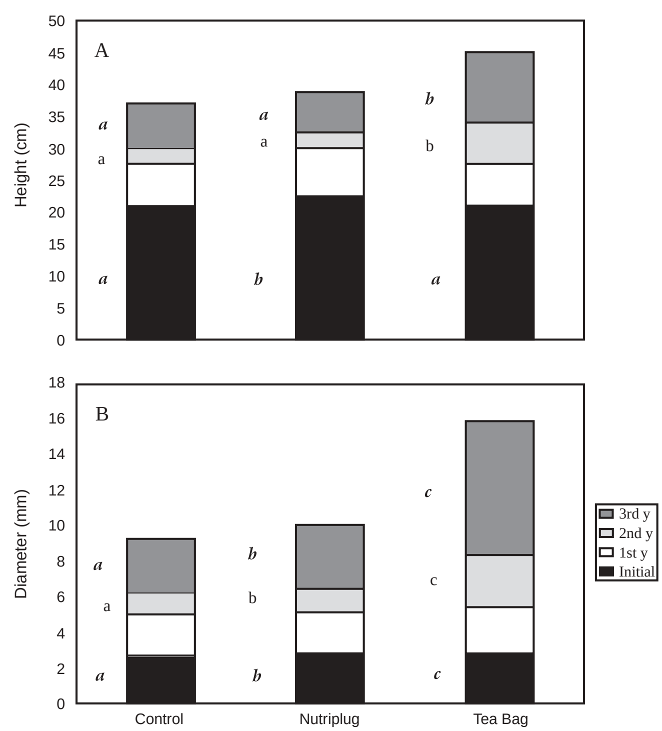

Figure 3—Height measurements (A) and diameter measurements (B) for the Tahtsa Reach trial after 3 seasons.

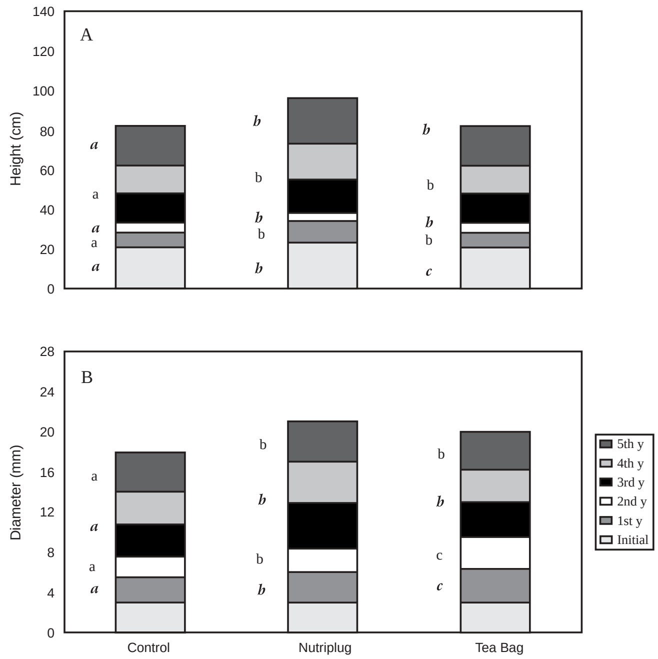

Figure 4—Height measurements (A) and diameter measurements (B) for the Whitesail trial after 5 seasons.

to the control throughout each of the first 5 growing seasons; no significant difference in height growth was found between the Nutriplug™ and "tea bag" treatments (Figure 4A). Initial diameter measurements were significantly greater in the "tea bag" treatment at outplanting and following the first and second growing seasons. Annual diameter growth was significantly greater for both the Nutriplug™ and "tea bag" treatments as compared to the control through the third, fourth, and fifth growing seasons, but no significant differences were found between the 2 treatments during these periods (Figure 4B).

Summer Outplanted Interior Spruce FAP—

Location: This trial was located near Dennis Lake in BC.

Treatments: Various commercially available CRFs were tested in conjunction with a control and the "tea bag."

1. Control. The control seedlings were those produced under operational culturing procedures (C).
2. Nutriplug™ FAS. Nutricote $16N{:}10P_2O_5{:}10K_2O$ CRF with a 12-month release formulation (at 25 °C [77 °F] soil temperature) (NT15).
3. Polyon $13N{:}13P_2O_5{:}13K_2O$ CRF with an 8- to 9-month release formulation (at 20 °C [68° F] soil temperature) (P13).
4. Polyon $17N{:}5P_2O_5{:}11K_2O$ CRF with a 10- to 12-month release formulation (at 20 °C [68° F] soil temperature) (P17).
5. "Tea Bag." Silva-Pak™ $26N{:}12P_2O_5{:}6K_2O$ (10 g [0.35 oz]) polymer-coated urea with a 12-month release formulation (at 21 °C [70 °F] soil temperature) (TB).

Results:

As reflected by the data in Figure 5, the use of fertilizer at the time of outplanting has an impact on survival. Most fertilizer treatments, with the exception of the P13 treatment, tended to lower overall seedling survival. This clearly displays the necessity of using the proper product and dosage in order to minimize the impact on survival and determine the point at which the gains outweigh the losses.

Results of height and diameter growth after 4 years for the Dennis Lake trial are shown in Figure 6. Initial seedling height was significantly greater in both the Polyon treatments as compared to the control and other treatments at

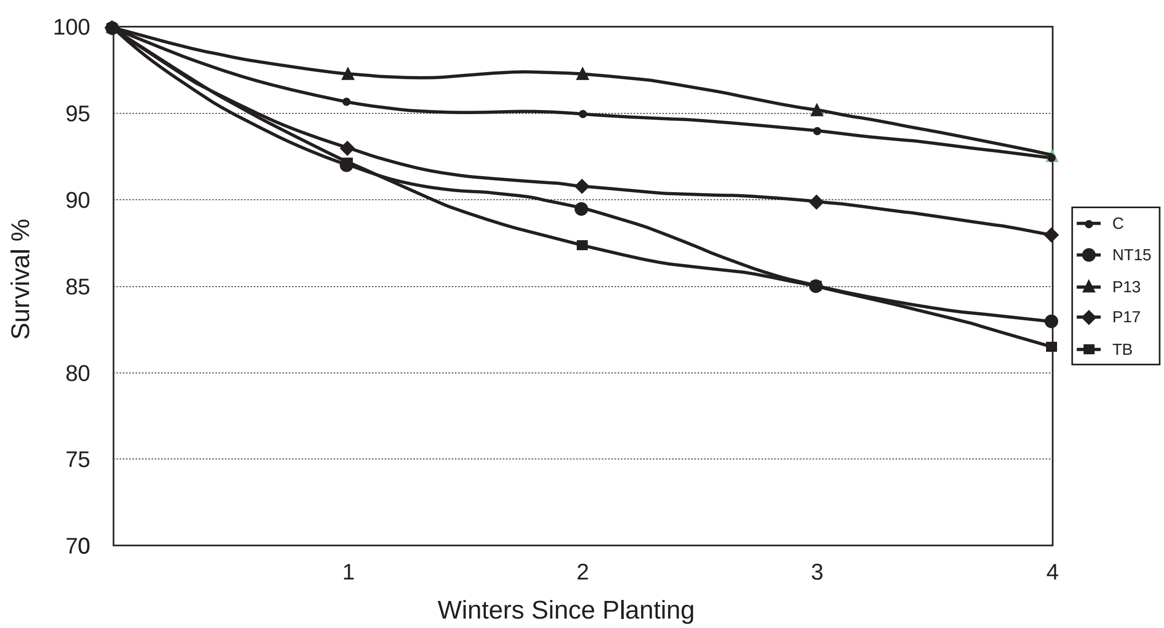

Figure 5—Survival after 5 years for the Dennis Lake trial.

outplanting. However, by the end of the third growing season, the 2 Polyon treatments differed, but there was no significant difference between the control and the other treatments in annual height growth (Figure 6A). Initial diameter measurements were significantly greater in both the Polyon treatments as compared to the control and other treatments at outplanting, and the P17 treatment resulted in significantly greater diameter growth at the end of the first season. At the end for the fourth growing season, annual diameter growth was significantly greater for the P17 treatment as compared the NT15 and TB treatments, but did not significantly differ from the control (Figure 6B).

Fertilization at Time-of-Lifting (FAL) Approach

In order to minimize the problems associated with the FAS Nutriplug™, PRT decided to develop a means to incorporate CRF into the plug at time-of-lift. The main objectives we are pursuing are:

1. Reduce the variation in the number of prills from plug to plug to enable us to increase the target average dose without generating undesirable salinity levels.
2. Ensure that all the fertilizer release takes place after outplanting in the field.
3. Identify new CRF products that would maximize the duration of the release time in the field.
4. Develop a mechanical means of incorporation consistent with our existing lifting equipment.
5. Target nutrient uptake via the root mass of the seedling and minimize feeding the surrounding vegetation.

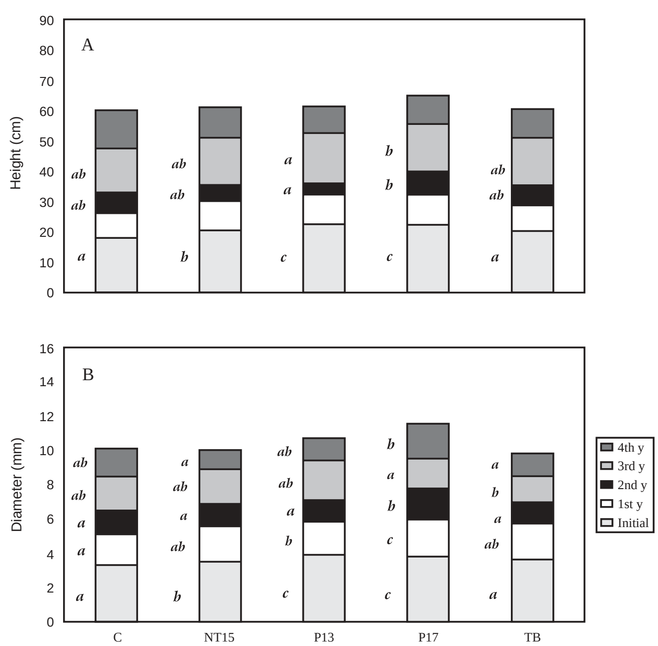

Figure 6—Height measurements (A) and diameter measurements (B) for the Dennis Lake trial after 4 seasons.

6. Provide a cost effective alternative to fertilization at the time of outplanting to our customers.
7. Ensure that the intellectual property is adequately protected.

Initial Incorporation Trial

In the spring of 2000, a large trial was implemented to evaluate the impact of various types and rates of CRF placed directly in the seedling root plug. The primary objective was to evaluate at which rate the various fertilizers would start to generate undesirable salt levels and thus negatively impact seedling survival. Ten products (or combination of products) were tested at 3 doses representing 0.5, 1.0, and 2.0 g N/80 ml (5 in^3) plug (Styroblock® PSB410A) interior spruce root-plug. The resulting 31 treatments (including the control) were outplanted as an operational trial on a forestry cutblock. All fertilizer treatments were individually weighed and inserted into small paper envelopes. At the time of outplanting, the envelopes were opened and the fertilizer was placed directly into contact with the root plug, then placed into the planting hole along with the opened envelope. The seedlings were assessed for survival after flushing in the spring of 2001. The high mortality rates anticipated for some of the treatments did not materialize and survival was good (Table 1).

Second Incorporation Trial

In order to validate the results obtained from the original trial, a second incorporation trial was implemented using the same fertilizer treatments. However, this trial was different in that the fertilizers were pre-incorporated in a manually created cavity from the bottom of the plug during fall lifting at the nursery. The seedlings were then packaged and cold stored for the duration of the winter (–2 °C [28 °F]) as per our current practices. Outplanting took place in the spring of 2002, which was much drier than average. Survival was evaluated in the fall of 2002. Although we still have missing data, the survival rates were much more in line with our original expectations, demonstrating the negative impact of extended (that is, cold) storage and a dry year on fertilizer salts within the root plug. Increased mortality was as expected, and was correlated with the increasing doses (Table 2). This trial is still providing us with valuable information as to the maximum fertilizer rate of the various products that would remain safe even in an exceptionally dry year. Our preliminary results indicate a positive growth response for most of the treatments. Statistics will be compiled after measurement in fall 2003.

Development of a Mechanized Means of Incorporation (FAL)

Concurrent to this trial work, PRT has been working on the development of a mechanized means of incorporating fertilizer in root plugs at the time of lifting. In fall 2001, a prototype was developed to inject seedlings on a semi-operational basis. A field trial was replicated in an operational setting in BC and Saskatchewan. The treatments

Table 1—Survival evaluation of different fertilizer treatments with hot lifting, spring outplanting, and fertilizer incorporation into the planting hole on 3 different sites.

Fertilizer mix number	Fertilizer application rate (g of fertilizer per plug)	Fertilizer application rate (g of N per plug)	Survival on site 1	Survival on site 2	Survival on site 3
			----------	*percent*	----------
1	1.3	0.5	100	100	100
2	2.5	1	100	100	93
3	5.1	2	99	93	88
4	2.9	0.5	100	100	100
5	5.7	1	100	100	99
6	11.4	2	99	100	93
7	2.9	0.5	100	100	99
8	5.9	1	100	100	97
9	11.8	2	100	100	97
10	3.7	0.5	100	100	100
11	7.4	1	100	100	100
12	14.8	2	100	100	97
13	2.2	0.5	100	100	100
14	4.3	1	100	100	100
15	8.6	2	97	97	97
16	3.1	0.5	100	100	100
17	6.3	1	100	100	100
18	12.5	2	100	100	99
19	1.4	0.5	100	100	99
20	2.9	1	100	100	100
21	5.8	2	100	100	92
22	1.6	0.5	100	100	99
23	3.2	1	100	100	100
24	6.5	2	99	100	97
25	2.3	0.5	100	100	100
26	4.6	1	100	100	100
27	9.1	2	99	100	100
28	2.4	0.5	100	100	100
29	4.7	1	99	100	100
30	9.5	2	100	100	99
			100	100	97

were refined and considerably narrowed down. The doses were readjusted in the range of 0.2 to 0.5 g N/plug (1.0 to 3.0 g of fertilizer) for the 80 ml (5 in^3) plug of a 410A block (Table 3).

Although spring 2002 was mostly dry, survival was in a much more acceptable range for all treatments (Figure 7A). Early measurement in fall 2002 indicated a positive effect on growth (Figures 7B and 7C). A thorough statistical analysis will be done when measurement takes place in fall 2003.

Conclusion

Although in its early stages, we believe the FAL Nutriplug™ technology has the potential to become a very useful silvicultural tool by helping tree seedlings overcome any “planting check” experienced during their first 2 or 3 seasons, thus quickly achieving optimal growth. Although the doses and suitable products have been narrowed down considerably, more research is needed to further define what fertilizer is best suited for a given combination of species, containers, and outplanting sites.

The development of a fully automated injection machine is also part of our current agenda, so that we will be able to fill high-volume orders through a technology fully compatible with our existing lifting equipment.

We see FAL technology (patent pending) taking the Nutriplug™ to the next generation. As a cost effective and versatile alternative to FAP, it also has the flexibility of being able to deliver various products in a range of doses directly to the root plug. This opens the door to a multitude of applications and outplanting sites, with seedling fertilizer effectively customized for each application.

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Table 2—Survival evaluation of different fertilizer treatments with fall lifting, fertilizer incorporation into the plug, cold storage, and spring outplanting on 2 different sites.

Fertilizer mix number	Fertilizer application rate (g of fertilizer per plug)	Fertilizer application rate (g of N per plug)	Survival on site 1	Survival on site 2
			- - - - - *percent* - - - - - -	
1	1.3	0.5		46
2	2.5	1		0
3	5.1	2		2
4	2.9	0.5		32
5	5.7	1		8
6	11.4	2		0
7	2.9	0.5		50
8	5.9	1		16
9	11.8	2		2
10	3.7	0.5		42
11	7.4	1	8	
12	14.8	2	58	
13	2.2	0.5	75	
14	4.3	1	33	
15	8.6	2	50	
16	3.1	0.5	50	
17	6.3	1	8	
18	12.5	2	25	
19	1.4	0.5	25	
20	2.9	1	8	
21	5.8	2	58	0
22	1.6	0.5	92	100
23	3.2	1	75	100
24	6.5	2	92	60
25	2.3	0.5	50	93
26	4.6	1	8	3
27	9.1	2	42	0
28	2.4	0.5	75	97
29	4.7	1	58	43
30	9.5	2	67	10
			92	100

Table 3—Treatments for mechanized incorporation for fertilization at time of lifting.

Mix number	Fertilizer	Nitrogen
	- - - - - - *g per plug* - - - - - -	
1	1.029	0.180
2	1.487	0.260
3	2.002	0.350
4	1.000	0.170
5	1.500	0.255
6	2.000	0.340
7	1.554	0.202
8	2.077	0.270
9	3.108	0.404
10	1.000	0.160
11	1.500	0.240
12	2.500	0.400
13	1.000	0.310
14	0.000	0.000
15	0.000	0.000

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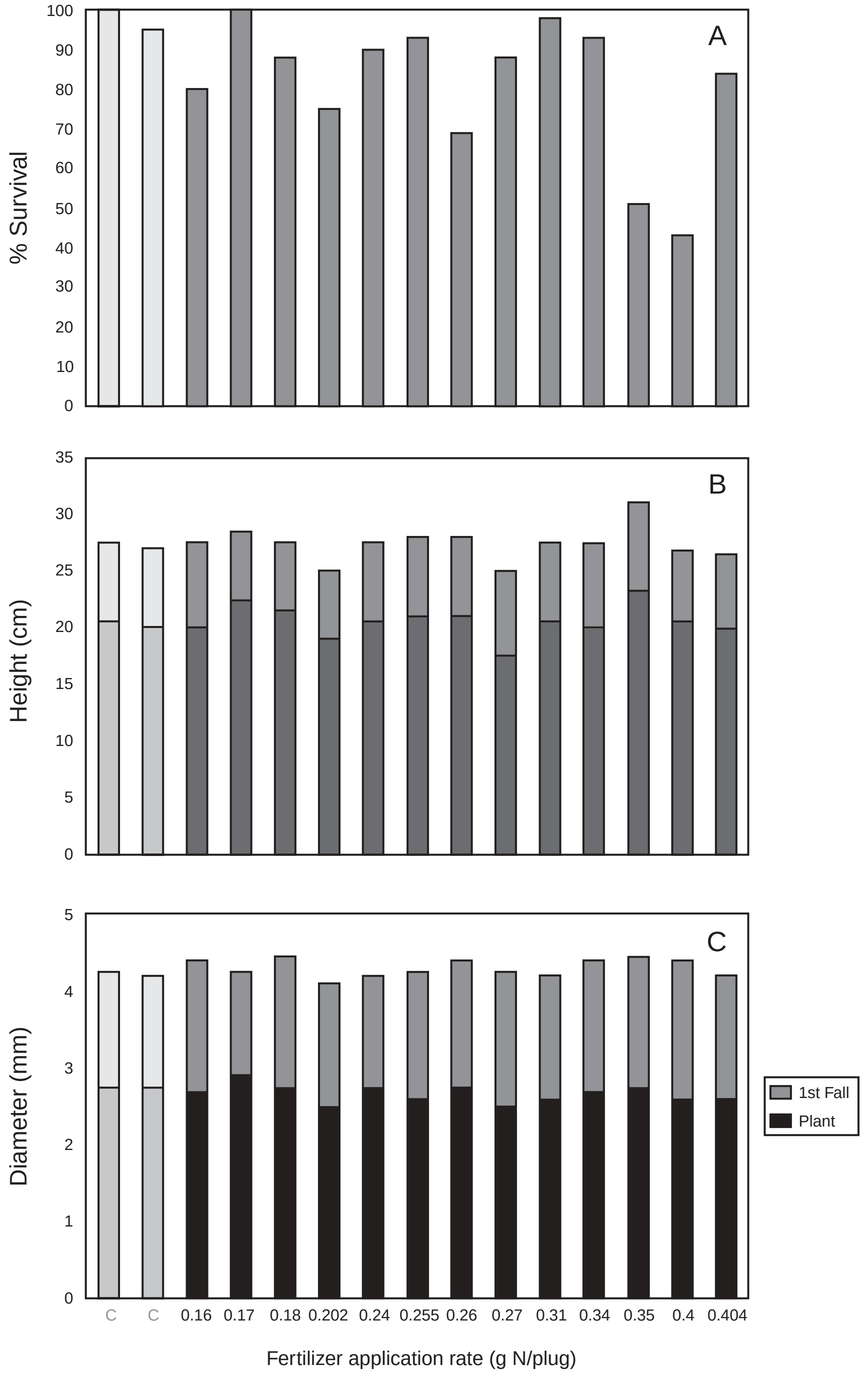

Figure 7—Survival percent (A), height measurements (B), and diameter measurements (C) for interior spruce at the Telkwa site after 1 growing season for the mechanized FAL trial.

Fate of Nitrates in Field Nursery Production Systems

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Abstract: Nitrogen (N) fertilization is an integral part of managing field nursery production. However, growers must manage additions properly in order to optimize growth efficiency and avoid environmental impacts. In particular, leaching of nitrates below the crop root zone and into ground water is an increasing concern. Historically, field nurseries have often been located in areas with coarse-textured soils to facilitate seedling lifting and other nursery operations. These soils typically have low nutrient-holding capacities requiring frequent N inputs that may be subject to leaching. This paper will review the principle inputs and outputs in the N cycle of a typical nursery and the environmental concerns associated with nitrate leaching. We will discuss the results of our case studies of nitrate movement in field nursery systems in western Michigan and suggest management practices that growers may adopt to improve N use efficiency and reduce environmental impacts.

Keywords: ground water contamination, eutrophication, nitrogen balance, fertilization, plant mineral nutrition

Introduction

Leaching of nitrates and other contaminants has been recognized as a significant environmental issue in container production systems (Dumroese and others 1992, 1995; Dumroese and Wenny 1992; Juntunen and others 2003). Total nitrogen (N) concentrations of leachate from container nurseries may exceed 500 mg/l (0.019 oz/gal) (Juntunen 2003), and up to 60% of N applied to container nurseries may be lost in discharge water (Dumroese and others 1995).

Leaching of nitrate below the crop root zone and into ground water is an increasing concern in field nursery production systems as well. Studies of agronomic field crops suggest that 20 to 100 kg/ha (18 to 89 lb/ac) may leach to ground water each year (Powlson 1993). Historically, field nurseries have often been located in areas with coarse-textured soils to facilitate seedling lifting and other nursery operations. These soils typically have low nutrient-holding capacities requiring frequent N inputs that may be subject to leaching.

The Nitrate Problem

Nitrate is the pollutant most commonly identified in ground water. Though nitrate (NO_3^-) is the main form in which N occurs in ground water, dissolved N may also be present as ammonium (NH_4^+), nitrite (NO_2^-), nitrogen (N_2), nitrous oxide (N_2O), and as organic N (Burt and others 1993).

Agricultural practices are responsible for a major portion of the nitrate pollutants in surface water (Cooper 1993). In the UK, 1.6 million tons (1.45 million tonnes) of N are applied to crops as fertilizer every year, 10 to 60% of which is not incorporated by the crop (Sylvester-Bradley 1993). These non-point pollutants are difficult to measure, control, and regulate because they originate from a diffuse area, are generally not continuous, and can vary depending on weather and time of year. Any control requires altering land management practices (Carpenter 1998).

It has been shown that with agricultural crops, it takes a large amount of fertilizer to bring a crop to its maximum yield; indeed, to increase yield from 90% of maximum to 100%, doubling the fertilizer N is required to provide the last 10% of the yield (Sylvester-Bradley 1993). Because fertilizer is relatively inexpensive in terms of overall production costs, growers may over-apply to ensure that the crop will grow to its maximum potential. However, total N in the soil is often underestimated. Nitrogen can derive from a combination of organic compounds already present in the soil, can be released from mineralization of applied manure, or from non-organic fertilizers (Figure 1). The underestimation of available N can lead to a surplus of N in the soil and major contamination of ground water by large quantities of N (nitrate) in leachates (Powlson and others 1992; Shepherd and others 1996; Alt 1998; Goulding 2000). In the world's croplands, additions and removals of nutrients by humans have overwhelmed natural nutrient cycles. Worldwide, more nutrients are added as fertilizers than are removed by crops (Carpenter 1998).

Harm to Humans

The most susceptible individuals to the harmful effects of the ingestion of nitrates are infants under the age of 6 months.

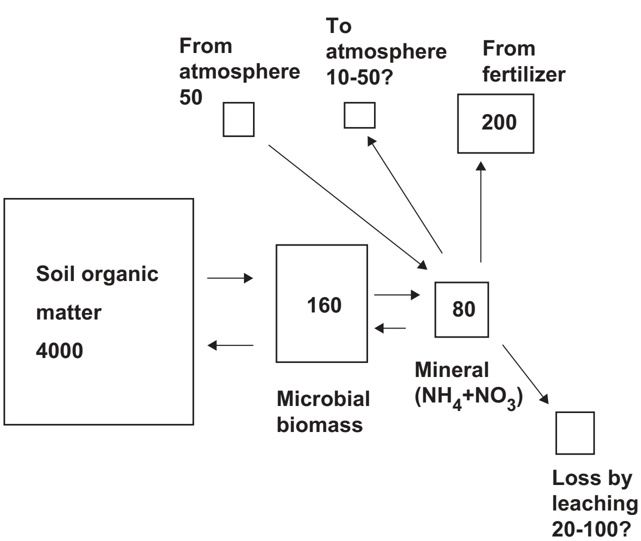

Figure 1—Nitrogen pathways in soil. The quantity of nitrogen in each pool (kg/ha) or undergoing each process (kg/ha/yr) is proportional to the size of the square (Powlson 1993) (1 kg/ac = 0.9 lb/ac).

Adults and older children can excrete ingested nitrate through their urine. Other groups at risk are pregnant women, cancer patients, and people with reduced stomach acidity (Carpenter 1998; Mahler and others 1991). Infants under the age of 6 months have low levels of acid in their digestive tract. To help with digestion, they have high levels of bacteria, which convert nitrate to the toxic nitrite (Mahler and others 1991). In the bloodstream, nitrite combines with hemoglobin and forms methemoglobin. Unlike hemoglobin, this compound is unable to carry oxygen. As more methemoglobin is produced, suffocation starts to take place from the lack of oxygen. This is called "methemoglobinemia" (Mahler and others 1991). When babies contract this it is termed "blue-baby syndrome." To protect babies less than 6 months old, the US Environmental Protection Agency has established a maximum contaminant level for nitrate in drinking water of 10 mg/l (Carpenter 1998).

Nitrate may also interact with organic compounds to form nitrosamines, which are known to cause cancer. Compounds that can interact with nitrate include some pesticides. This is important because areas contaminated with nitrates have a high probability of containing pesticides (Mahler and others 1991).

Effect on Aquatic Ecosystems

Eutrophication is defined by Carpenter (1998) as "the fertilization of surface waters by nutrients that were previously scarce." The nutrients that cause the most harm in this process are phosphorus and N. Eutrophication is currently the most widespread water quality problem in the US, and in many other nations.

There are severe consequences to eutrophication which include: premature aging of lakes, proliferation of algae, increase in bacterial populations, decrease in dissolved oxygen, and fish kills. Eutrophication is part of the aging process of shallow lakes. With the increase in plant and algae populations in a lake system there is also an increase in dead plant material, which causes the bacterial decomposer population to increase dramatically. These bacteria consume dissolved oxygen, leaving an inadequate supply for fish and causing fish kills (Carpenter 1998).

Protecting surface and ground water quality is critical for the nursery industry, an industry that generates over US $700 million in annual sales in Michigan alone. Approximately half of the acreage in nursery production in Michigan is concentrated in 4 western counties near Lake Michigan. Soils in this area are coarse textured, have low organic matter, and are therefore vulnerable to nitrate leaching. Nitrogen addition rates for some high N-demanding nursery crops, such as *Euonymus alatus* 'Compactus', may range as high as 250 kg/ha (223 lb/ac). Estimating N losses from field production systems can be problematic compared to container systems. In container systems, a mass balance analysis can be used to develop a "check book" approach to account for N additions and losses (Dumroese and others 1995). In field systems, N fluxes are often difficult to estimate.

Specific Objectives and Hypotheses

In the present study, we tested the hypothesis that scheduling N applications to meet crop demand will result in optimal growth and reduce nitrate movement to ground water. The research applied Ingestad and Ågren's principle of relative addition rate (Ingestad and Ågren 1988, 1992) to nursery production as proposed by Alt (1998a,b) and Dumroese and others (1995).

Based on Ingestad and Ågren's theory, plant mineral nutrition is optimized when nutrient supply, either from native soil fertility or nutrient additions, is in balance with plant nutrient demand. A mitigation to the application of Ingestad and Ågren's concepts to field crops is the logistical difficulty of estimating nutrient demand of a standing crop. Recently, however, Alt (1998a) demonstrated that the N demand of nursery crops can be reasonably estimated from the total fresh weight of new shoots.

Specific objectives:

1. Evaluate impact of 3 fertilization approaches on:
   a. crop nutrition and growth;
   b. nitrate concentration of water under root zone;
   c. nitrate concentration of shallow ground water.
2. Develop baseline data on impact of nursery operations on ground water.
3. Determine the validity and logistics of applying relative addition rate principles to nursery crops.

Methods

Treatments

We established fertilization plots in Japanese yew (*Taxus* x *media*) and burning bush (*Euonymus alatus* 'Compactus') fields in 2 commercial nurseries in Ottawa County, Michigan, in the spring of 2001. Three replicate plots in each field were assigned to 1 of 3 fertilization treatments:

1. Control—no additional fertilization.
2. Operational—fertilization based on industry standard (150 kg N/ha [134 lb/ac] split into 2 applications [April and July]).
3. Relative addition rate (RAR)—fertilization based on crop growth rate. Crop biomass growth was estimated from periodic measurements of crown volume (Figure 2). Nitrogen uptake was estimated as the change in standing crop N between measurement periods. Nitrogen was added to replace the amount taken up assuming 50% uptake efficiency.

Data Collection

Foliar samples were collected from each plot on a monthly basis and analyzed for N concentration.

Two porous-cup suction lysimeters were installed to a depth of 45 cm (18 in) near the center of each plot. The vacuum on each lysimeter was set to 0.70 mbar (70 Pa), and soil water samples were collected after each significant rainfall during the 2001 growing season (Figure 3).

Figure 2—Seasonal changes in plant biomass were estimated from periodic measurements of crown volume.

Figure 3—Soil water sampling with a suction lysimeter.

Results

Nitrate Leaching

Nitrate concentrations of soil water collected in the lysimeters were affected by species and fertilizer treatment. In the *Taxus* fields, fertilization significantly increased soil water nitrate concentration below the root zone relative to the control (Figure 4). Soil water nitrate in the RAR plots were intermediate between the control and the operational treatment. Soil water nitrate levels were higher in the *Euonymus* than the *Taxus*, particularly on the control plots. Since the *Euonymus* fields were younger than the *Taxus* plots, this effect may reflect mineralization of residual organic matter from manuring and cover crops during the fallow period prior to plantation establishment. Nitrate levels in soil water ranged from 10 to 150 mg/l (0.001 to 0.02 oz/gal) in the *Euonymus* plots and from near zero to 100 mg/l (0.013 oz/gal) in the *Taxus* plots.

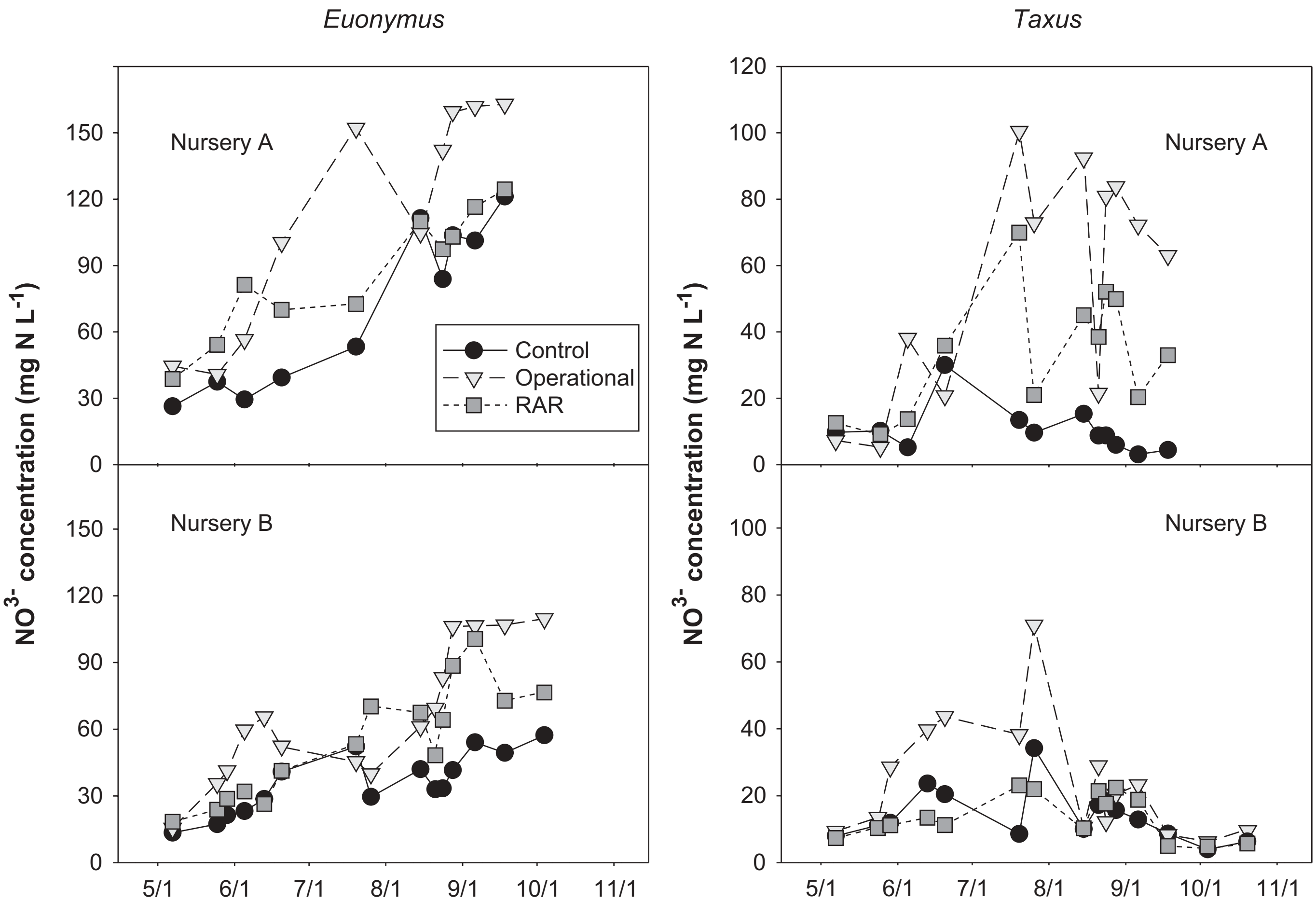

Figure 4—Soil water nitrate concentration of samples collected at 45 cm (18 in) depth in field nursery plots of *Euonymus alatus* 'Compactus' and *Taxus* x *media* grown under three levels of fertilization.

Growth and Foliar Nutrition

Crown volume growth of *Euonymus* and *Taxus* did not differ ($P > 0.42$) among the fertilization treatments (data not shown). Fertilization increased foliar N levels relative to the controls in *Taxus* but not *Euonymus*. Vector analyses indicated luxury uptake of N in the *Taxus* plants (Rios 2002).

Conclusions

Overall the results of this study indicate that growth of nursery crops can be maintained, and nitrate losses reduced, by matching N additions to crop demand. Moreover, a better understanding of the overall N balance in field nursery crops is needed to further optimize crop growth and quality while minimizing N losses and adverse environmental impacts. Nursery managers need to consider crop species, age, and growth habit in developing nutrient prescriptions. Our research indicates attention needs to be paid to:

1. Understanding mineralization rates and other factors controlling availability of N besides fertilizer additions. In our study, the nonfertilized controls grew as well as either of the fertilized treatments in both species. This raises the questions of how long N supply from mineralization of organic matter can meet crop demand.

2. Crop growth and development. In the present study, *Euonymus* has a determinant growth habit, completing crown growth by mid-July. In contrast, the *Taxus* plants continued to grow late into summer depending on availability of soil moisture. This suggests that *Taxus* would be better able to take advantage of late season N additions than the *Euonymus*. Also, more detailed information of total crop demand for N can help guide fertilization decisions.

3. Importance of other N forms, particularly organic N. Dissolved organic N can be an important component of agricultural N losses (Murphy and others 2000). Juntunen and others (2003) found that organic N may contribute over half of the N in soil water beneath container forest nurseries during the spring. Organic N is also being recognized as an important source of N for plant uptake in various ecosystems (Näsholm and others 2000; Näsholm and Persson 2001).

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Considerations for Collecting and Vegetatively Propagating Poplar Woody Plant Materials

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Keywords: dormant cuttings, rooted cuttings, genetic diversity, biodiversity, restoration

Most Important

Vigorous, healthy plant material at the end of the vegetative propagating process is directly dependent upon vigorous, healthy plant material being used to begin the process. If vigorous, healthy plant material is not available, it will need to be created.

Essential Points

- A clearly defined end product (that is, dormant cutting/rooted plant, bareroot/container, size, and so on) needs to be determined prior to initiating a propagation project.
- Only use vegetative growth from the most recent year's vegetative growth to make dormant cuttings for field planting or greenhouse/nursery propagation.
- Know the difference between floral and vegetative buds. This is particularly important in determining the sex of dioecious species.
- Only collect stems with healthy, intact vegetative buds. Intact vegetative buds are buds at leaf scars (that is, the bases of the prior year's leaf stems) along the stem of branch material to be used in propagation that have not been damaged or broken off, and that have not become short shoots or small branches. *Stems with obvious disease and insect damage should not be used*.
- When making cuttings for planting, it is absolutely essential to have a healthy, intact vegetative bud within the top 1 in (2.5 cm) of the cutting regardless of the cutting length. It is very important for the people doing the onsite collections to clearly understand how the material will be subdivided and propagated to be effective and efficient in their collection efforts.
- In general, dormant cuttings can be collected in January/February, but may be collected outside this timeframe depending on the overall weather conditions at a specific site. Vegetative material where bud elongation has begun, or that is in an active growing stage, can only be propagated under extremely controlled conditions (that is, usually in a greenhouse or nursery).
- Dormant cuttings/stem sections should be sealed in plastic and stored at temperatures slightly below freezing (28 to 30 °F [–1 to –2 °C]). *Note that home freezer temperatures are considerably below freezing (–10 to 10 °F [–10 to –20 °C]). Storing dormant cuttings in home freezers may result in severe damage, even death, to the cuttings.*
- Dormant cuttings/stem sections should not be refrigerated at temperatures above freezing, or even slightly above freezing, for more than 1 to 2 weeks.

Questions to Consider

- Why is vegetative propagation of plant material being considered? Convenience? Cost? Is your focus on function as opposed to biodiversity or genetic diversity? Is this the only technique you are aware of?
- What are you ultimately trying to achieve with the choice of vegetative propagation?

- What are the overall objectives for rehabilitation, restoration, revegetation?
- Are biodiversity and genetic diversity important issues in rehabilitation, restoration, revegetation? Should biodiversity and genetic diversity be important considerations in rehabilitation, restoration, revegetation?
- Are there deployment strategies for clones and separate sexes of dioecious plants (that is, poplars and willows) in your rehabilitation, restoration, revegetation efforts? Is current population status/structure being considered? Is there a conscious attempt to collect both male and female material from dioecious plants?
- Should consideration be given to other plant propagating techniques to meet the overall objectives, such as breeding, collecting seeds, and growing seedlings?

Restoration of a Rocky Mountain Spruce-Fir Forest: Sixth-Year Engelmann Spruce Seedling Response With or Without Tree Shelter Removal

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Abstract: This paper presents results following 6 growing seasons of a project designed to examine the use of tree shelters as a means to provide initial shade for planted Engelmann spruce seedlings. Seedlings were planted in 1996 on a 48-ha (119-ac) high-elevation site with different colors of tree shelters providing various degrees of shading. A control treatment, consisting of shading using debris within the site, was also included. Results following 2 years were presented previously (Jacobs and Steinbeck 2001). To examine the response of seedlings to shelter removal following seedling establishment, 50% of shelters were removed in 2000 and all seedlings were re-measured in 2002. Shelter removal did not result in mortality, indicating that seedlings are able to grow in full sun after 4 years. Survival to 2002 of all shelter treatments (with or without shelter removal) was ≥ 88%, while survival of the control was 45%. For all 3 shelter colors, shelter removal resulted in less mean height growth but greater mean diameter growth. The lightest color tree shelter (with or without removal) produced the best overall response. Because shelters showed little sign of deterioration after 6 years, it was suggested that shelters could be removed at 4 years and reused at a different site. Tree shelters appear to provide a viable and cost-effective option to restore high-elevation spruce-fir sites where reforestation has proven difficult in the past.

Keywords: forest restoration, reforestation, tree planting, gopher browse, seedling shading, Colorado, *Picea engelmannii*

Introduction

The high-elevation forests of the central and southern Rocky Mountains are comprised primarily of Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) (Figure 1) and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.). Little harvesting pressure occurred in this region prior to about 1950 due to the relative inaccessibility of these forests and an abundance of large-diameter ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) at lower elevations. As the supply of ponderosa pine dwindled, forest managers turned to the high-elevation forests to supply timber needs. Engelmann spruce proved to be a desirable timber species due to its lightweight, yet durable wood properties. Harvesting increased dramatically following a large-scale epidemic of the spruce bark beetle (*Dendroctonus rufipennis* Kirby), which killed over 14 million m^3 (494 million ft^3) of timber by 1951 (Markstrom and Alexander 1984). Harvesting, primarily to salvage infected trees, increased by nearly 1,000% from 1949 to 1956 (Markstrom and Alexander 1984).

Harvesting was generally accomplished using clearcutting, and openings greater than 50 ha (124 ac) were not unusual. Natural regeneration following harvesting in these forests was typically poor (Ronco and Noble 1971), with the exception of small (1 to 2 ha [2.5 to 5 ac]) cuttings on northern aspects, which contained exposed mineral soil (Alexander 1983, 1984). Subsequent research indicated that shade-tolerant Engelmann spruce seedlings require shading for optimal development, typically exhibiting chlorosis in the absence of shade (Ronco 1970a,b,c). Essentially, high light intensities act to damage the photosynthetic mechanism of unshaded seedlings and as a result, seedlings become chlorotic and often die.

Currently, most harvesting in the high-elevation spruce-fir forests of the Rocky Mountains is conducted with small group selection cuts (Figure 2). Cuts should be less than 100 to 160 m (330 to 525 ft) wide, and mineral soil should be exposed to stimulate germination (Noble and Ronco 1978). Due to the general absence of natural regeneration on large clearcut sites

Figure 1—Mature Engelmann spruce.

Figure 2—Small group selection harvest, typical of current logging systems in the high-elevation spruce-fir forests designed to provide adequate shade to promote regeneration.

Figure 3—Typical large clearcut established to remove beetle-infested timber that currently exhibits poor stocking despite previous planting attempts.

(Figure 3), however, extensive planting efforts were made following the publication of a guide to artificial reforestation of Engelmann spruce. In this guide, Ronco (1972) recommended that seedlings be planted to the northeast of protective shade cover (that is, stumps, logs, slash, or live vegetation). Regardless, survival on many sites has been poor and many sites are planted repeatedly in an attempt to reach the USDA Forest Service (USFS) stocking requirement of 375 live trees/ha (150 trees/ac). Mortality has been attributed to a number of factors, including drought (Hines and Long 1986); but clipping of tops by gophers (*Thomomys talpoides*) has been a consistent problem (Ronco 1967). Poor seedling establishment has prompted the USFS to abandon reforestation efforts on some sites. This has occasionally led to a change of land classification from forest to meadow.

This paper reports on sixth-year results of a project designed to examine the use of tree shelters as a means to improve Engelmann spruce seedling planting success. Tree shelters were designed in 1979 by Graham Tuley to provide browse protection for oak (*Quercus* spp.) seedlings (Potter 1988). However, added benefits were realized when sheltered seedlings survived and grew faster than unsheltered seedlings (Tuley 1983, 1985). This was later attributed to an apparent greenhouse effect, in which temperature and relative humidity are increased compared to ambient conditions (Kjelgren and others 1997). In the current study, it was hypothesized that shelters would provide adequate shading for seedling establishment, decrease incidence of gopher browsing, and increase seedling growth. These hypotheses were affirmed, and results following 2 growing seasons were reported previously in Jacobs and Steinbeck (2001).

This study was continued to monitor long-term seedling survival and growth response to establishment in tree shelters. Although it is well-documented that Engelmann spruce seedlings need shade initially, it is not definitively known at what point seedlings are able to grow in full sun. Seedling growth response and biomass allocation following removal versus presence of tree shelters after establishment is also unclear. Additionally, although the tree shelters were designed to photodegrade after 5 years, it is important to determine the actual timeframe and mechanism by which the shelters degrade. These were the objectives of the current report following 6 field-growing seasons.

Materials and Methods

Characteristics of the research site and methodology for study establishment were thoroughly described previously (Jacobs and Steinbeck 2001). In summary, seedlings were planted in fall of 1996 on a 48-ha (119-ac) site at approximately 3,273 m (10,738 ft) that was clearcut in 1971 to salvage beetle-infested timber. Following failed natural regeneration, the site was planted in 1976 and 1985 without reaching desired stocking. The entire unit was again planted in 1996, simultaneously with the establishment of this study. Treatments included 4 different tree shelter (Tree Pro®) colors (allowing different levels of photosynthetically active radiation [PAR] to reach the seedlings) and a control which involved the traditional method of shading seedlings with debris within the site. Seedlings were planted into 3 blocks, with 4 plots of each treatment randomly located within a block. Each plot contained 25 seedlings.

Treatment differences following the first 2 years were prominent. The darkest shelter color resulted in 95% mortality and was disregarded from growth analyses. The lightest 3 shelter colors resulted in >95% survival after 2 years, compared to 58% for the control treatment. The majority of mortality in the control was attributed to browse by gophers. Total seedling height, new leader growth, and total diameter were also greater for sheltered trees following 2 growing seasons. Shelters were recommended as an effective option for restoration of high-elevation spruce-fir sites in the Rocky Mountains.

In July of 2000, new treatments were installed. In each block, 2 of the 4 plots with sheltered trees were randomly selected for shelter removal. Shelters on seedlings in the remaining plots were not removed. In July of 2002, all seedlings were assessed for survival and remeasured for total height/root-collar diameter (Figure 4). Incidence of terminal bud death was also recorded to determine if seedlings were more likely to experience frost damage in shelters. Health status of seedlings was also recorded using the same methodology as that in the original report. Deterioration of shelters was also observed.

Data were analyzed using a one-way analysis of variance (ANOVA) with 7 treatments. The treatments included the 3 shelter colors with shelters remaining (listed as A, B, and C from lightest to darkest color), the 3 shelter colors with shelters removed, and the control. If the ANOVA indicated significant differences ($P = 0.05$ in F test) among treatments for a parameter, Fisher's Protected LSD procedure was used to determine significant differences among parameters. The sampling unit was an individual seedling and the experimental unit for analysis was the mean parameter value for seedlings within a treatment block.

Results

After 6 years, survival differed among treatments ($P < 0.0001$) with the control having significantly lower survival (45%) than any other treatment (Figure 5). Survival did not

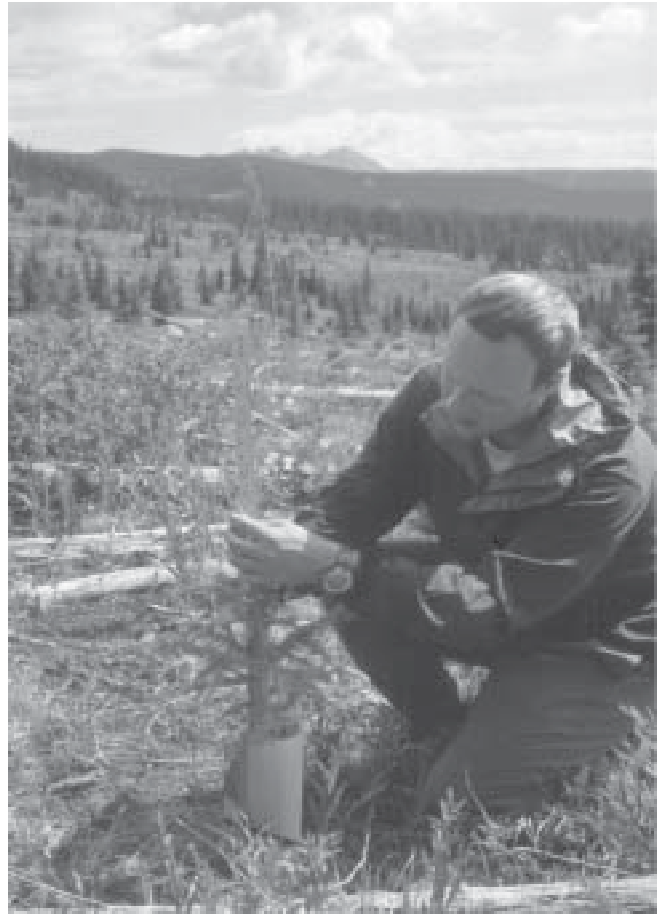

Figure 4—Measurement of sheltered seedling in 2002.

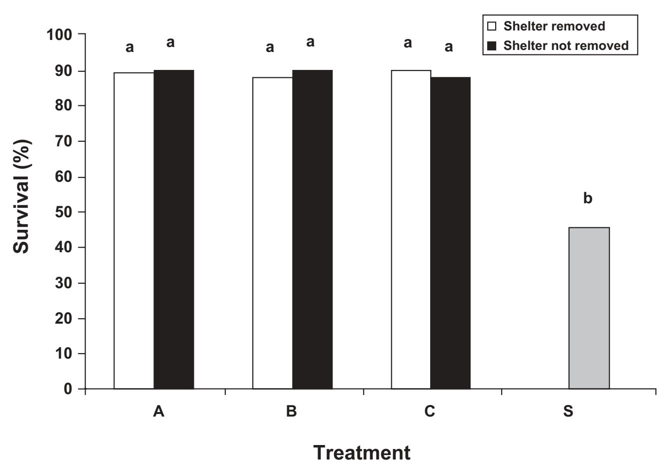

Figure 5—Seedling survival to 2002. Treatment letters A through C represent the shelter colors from lightest to darkest color, and treatment S is the control. Treatments with different letters above the bars are significantly different at $\alpha = 0.05$.

differ among other treatments and these treatments all had survival = 88%. The majority of mortality at this point was attributable to physiological causes, with little mortality identified as being due to gopher browsing. Diameter growth (P = 0.0004) (Figure 6) and height growth (P < 0.0001) (Figure 7) over the 6 years differed among treatments, and interesting trends were apparent. Shelter treatments, regardless of shelter removal or not, continued to show generally better growth than the control. All treatments had significantly greater height growth than the control. The lightest shelter color (A) had more diameter growth than the control regardless of removal or not. Treatment B with shelter removed also had greater diameter growth than the control. Examining each shelter color individually, shelter removal always resulted in less mean height growth and more mean diameter growth. Differences were significant for shelter color B for diameter growth and shelter colors A and C for height growth.

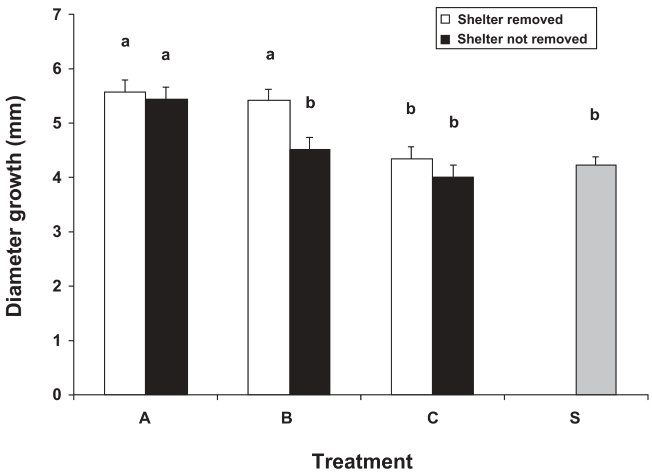

Figure 6—Diameter growth from 1996 to 2002. Treatment letters A through C represent the shelter colors from lightest to darkest color and treatment S is the control. Treatments with different letters above the bars are significantly different at α = 0.05.

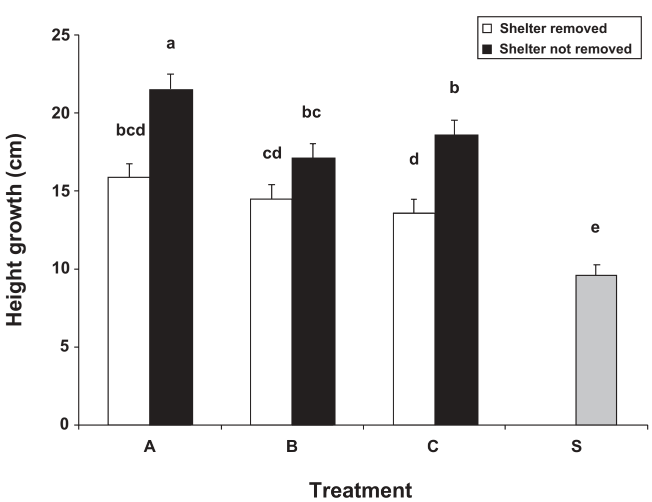

Figure 7—Height growth from 1996 to 2002. Treatment letters A through C represent the shelter colors from lightest to darkest color and treatment S is the control. Treatments with different letters above the bars are significantly different at α = 0.05.

Most surviving seedlings appeared healthy and exhibited good form (Figures 8 and 9). The percentage of healthy (that is, <5% yellowing/browning foliage and absence of mechanical damage) seedlings was greatest for treatments in shelter color A, regardless of removal, and B with removal (Figure 10). Shelter color C with removal had the lowest percentage of healthy seedlings. There was no significant difference in the percentage of trees with evidence of terminal bud death (P = 0.0755). Mean values for the percentage of trees with evidence of terminal bud death ranged from a low of 34% (shelter color A without shelter removal) to 56% (shelter color B with shelter removal). Observationally, tree shelters were surprisingly intact at this point with less than 5% of the shelters showing any signs of photodegradation.

Discussion

Sixth-Year Seedling Response

Tree shelter treatments continued to demonstrate enhanced seedling survival rates over the control treatment,

Figure 8—Healthy control seedling in 2002.

Figure 9—Healthy seedling in the lightest shelter color treatment in 2002.

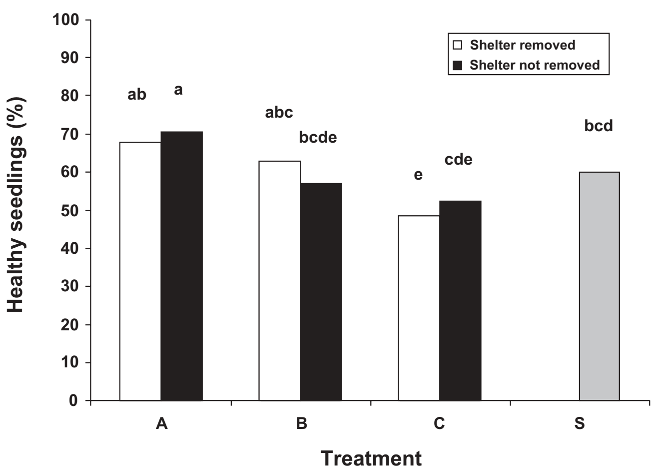

Figure 10—Percentage of healthy (that is, <5% yellowing/browning foliage and absence of mechanical damage) seedlings in 2002. Treatment letters A through C represent the shelter colors from lightest to darkest color and treatment S is the control. Treatments with different letters above the bars are significantly different at $\alpha = 0.05$.

and survival of seedlings following shelter removal was equally as good. All 6 treatments had survival = 88%. This is an exceptionally high survival rate following 6 years on this type of site and illustrates the benefit that tree shelters provided the seedlings during the establishment period. The 45% survival rate of seedlings in the control treatment is probably equal to or better than historic survival rates on these sites. These results affirm the positive influence of tree shelters on seedling survival reported by many other authors (for example, West and others 1999).

Shelter removal following 4 growing seasons did not result in differences in mortality as compared to sheltered seedlings. Though authors have speculated that seedlings should become adapted to high light levels after 1 or 2 growing seasons (for example, Feller 1998), I am aware of no quantitative information available to support this. This study showed that seedlings are adapted to survive in full sun after 4 years. The mechanism for this phenomenon is probably related to several factors. As needles age, the leaf cuticles thicken and become more resistant to damage from high light intensities. Additionally, more foliage is produced as the seedling grows, providing self-shading to the seedling.

Height growth of surviving seedlings was greater in all shelter removed or not removed treatments than the control. Diameter growth was greater in 3 of the 6 shelter removed or not removed treatments than the control. This again illustrates the benefit of tree shelters to seedling growth. Shelter removal promoted lesser height growth but increased diameter growth. This trend has been observed by other authors previously (Burger and others 1997; Gerhold 1999). Seedlings have limited reserves of energy to expend on the growth of various tissues. The reduction in available PAR light within the tree shelters promoted greater height growth to reach available light. This increase in energy devoted to height growth is accomplished at the expense of diameter growth.

Seedlings grown in shelter color A (with or without shelter removal) had the highest mean percentages of healthy seedlings, while shelter treatment C (with or without shelter removal) had the lowest. This may be associated with the degree of light reaching the seedlings. At this point in seedling development, the reduction of light in shelter C may have negatively affected health.

The treatments with the most ideal growth responses were probably treatments A (with and without shelter removal) and treatment B (with shelter removal). This is primarily based on differences in diameter growth, as diameter growth is well correlated with root system expansion. On these harsh, high-elevation sites, seedlings are adapted to grow an extensive root system to endure drought and recover from freeze damage of the shoot. It often takes 25 years for Engelmann spruce to reach 1.4 m (4.6 ft) in height (Alexander 1987). Thus, diameter growth is likely a more important morphological variable for assessment of seedling vigor than height. Given the shade tolerance of Engelmann spruce, it is possible that the lightest shelter color would also be the best choice for other more shade-intolerant conifer species.

Surprisingly, the tree shelters showed little indication of photodegradation and required minimal maintenance after 6 years. Evans (1996) reported that Tubex® shelters also did not deteriorate in the expected timeframe and recommended opening them to prevent growth restriction. In the present study, however, no restrictions to growth were observed, and it is possible that shelters will degrade before any type of growth restriction is evident.

Tree Shelter Cost Comparison

In 1996, cost of the Tree Pro® tree shelter and stake used in this study was US $0.95. Computing costs of labor and materials, planting at the current density would approximately double planting costs. However, the costs to the USFS to plant these sites using the traditional shading method is significant; in 1996, the estimated cost was US $1,075/ha (US $435/ac). This cost increases exponentially with each time a site must be replanted because of failed previous attempts. With survival rates >88% after 6 years (nearly double that of the control), it is likely that spacing could be reduced to alleviate the increase in planting costs. Additional benefit associated with improved growth rates would also be realized. On very harsh sites in the high elevation spruce-fir forests, the use of tree shelters (or a comparable method) may provide the only reasonable option for successfully restoring the site. Thus, on sites where reforestation has proven difficult in the past, tree shelters may be logistically appropriate and in some cases, modification of planting density may make their use economically competitive with traditional planting regimes.

Commitment to Restoration

The USFS and the public must consider to what extent the USFS should be held responsible for ensuring successful restoration of the large land area in the high-elevation spruce-fir forests that remains poorly stocked. In the case of the site used in the present study, an 800-km (500-mi) scenic trail (Colorado Trail) is positioned along the edge of the site. Though the San Juan Mountains section is often considered the most scenic portion of this trail, the presence of a poorly stocked 1971 clearcut is visually unattractive to many visitors. Visitors may develop a poor impression of the land stewardship character of the USFS. Though some people argue that a meadow is an adequate conversion of land use, return of harvested forests to forest land is preferable for many reasons.

Most modern-day foresters consider reforestation a necessity following timber harvest. In many areas of the country (for example, California, Oregon, Washington) reforestation in a timely manner is required by law. It is likely that over the course of 1,000 or 10,000 years, these high-elevation spruce-fir sites will begin to regenerate naturally. However, if reforestation prior to that timeframe is desired, steps must be taken by the USFS to ensure successful reforestation. Tree shelters offer a tested solution to promote establishment of Engelmann spruce seedlings.

If tree shelters are used on a large-scale, it would be advisable to develop a shelter that could reliably be installed at one site for a certain period of time (possibly 4 years, as exhibited in this study) and then removed for use at another site. This would lessen the potential environmental impact associated with discarded plastic shelters. The costs saved from eliminating the need to repurchase shelters should help to defray labor costs associated with shelter removal.

Summary

Tree shelters continued to show promise as a more effective alternative to the traditional shading method for restoration of high-elevation spruce-fir sites in the Rocky Mountains. It appears that Engelmann spruce seedlings are able to survive and grow well in full sun following 4 growing seasons, which provides the option of removing shelters at this point for use at a different site. Shelter removal generally resulted in increased diameter versus height growth, which may be a more desirable shift in growth resources to promote reforestation on harsh high-elevation sites. Because shelters deteriorated relatively little in 6 years, it is likely that they may be used at least twice, and costs (both financial and environmental) may be conserved by reusing shelters as opposed to leaving shelters to degrade on the site. In deciding on a shelter color for Engelmann spruce restoration, forest managers should understand the influence that shelter color has on growth response. A relatively light shelter color is probably ideal and darker colors should be avoided. This study will continue to be monitored to at least 10 years, and a followup report presented.

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Structure of Genetic Variation and Implications for the Management of Seed and Planting Stock

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Abstract: This paper reviews what is known about genetic structure of forest trees, and how that knowledge is used to determine safe limits to the movement of plant material. Geographic genetic variation in adaptive traits is of greatest importance to concerns of seed movement. Genetic structure in adaptive traits may be ascertained through long-term provenance and progeny tests, or short-term common garden studies in a nursery or nursery-like environment. These studies have shown that variation patterns are not consistent among species, among regions within a species, or among traits. The first seed zones were developed based on differences in climate and vegetation, and did not account for differences among species. Seed zones were recently revised in Oregon and Washington to reflect current knowledge of geographic genetic variation for individual species. Seed zones are an administrative convenience that directs managers how to bulk seeds from different stands. The use of seed transfer guidelines, on the other hand, allows greater flexibility and better knowledge of the risks of seed movement. Transfer guidelines, however, require keeping track of many small seed lots, which involves more time and expense.

Keywords: genetic structure, seed zones, breeding zones, seed transfer guidelines, genecology

Introduction

Genetic structure here refers to the organization of genetic variability among individuals within populations and among populations. Genetic structure determines, in part, the degree to which populations are adapted to the range of environments that they might face. Consequently, genetic structure is important in determining how far individuals from a population may be moved from their source environment and still ensure that a large proportion of them survive and thrive.

A seed zone is a region within which seeds or plants from native stands may be moved with minimal risk of maladaptation. Seed zones are delineated on maps with distinct geographic and elevational boundaries. Genetic variation in forest trees, however, changes gradually in most cases, and, thus, does not have distinct boundaries. For this reason, seed transfer guidelines are more appropriate. Seed transfer guidelines, also referred to as continuous seed zones, are procedures or rules for directing the most appropriate transfer of plant material from a point of origin to a planting site—in other words, for evaluating a number of potential transfers on the basis of relative risk of maladaptation.

A breeding zone is a region from which parents in a tree improvement program come, and to which the progeny from those parents are operationally planted with minimal risk of maladaptation. Thus, seed zones generally refer to plant material from presumably native stands, and breeding zones generally refer to plant material from tree improvement programs. The parents in a tree improvement program do not necessarily come from the same area that will be planted with the operational planting stock. For example, some second-generation parents in the Northwest Tree Improvement Cooperative (NWTIC) breeding program come from much further north or south of the area for which they are being tested and expect to be planted. To better distinguish the two, the collection of parents in a tree improvement program may be referred to as the breeding population, and the region to which the progeny are to be planted may be referred to as the deployment zone.

This paper reviews what is known about the genetic structure of forest trees and how that knowledge is used to determine safe limits to the movement of plant material, focusing primarily on the Pacific Northwest. We review reasons for seed/breeding zones and seed transfer guidelines, the methodology used to examine genetic structure, some generalizations about the genetic structure of forest trees, and the development of seed zones or transfer guidelines.

Reasons for Seed and Breeding Zones

Interest in planting in the Pacific Northwest arose around the beginning of the twentieth century following numerous, large fires. The Wind River nursery, one of the first Forest Service nurseries, was established in 1909, largely to help in reforestation efforts after the extensive Yacolt fire in southwest Washington. In the first few decades, little attention was given to the origin of seeds. Seeds were primarily collected from downed trees in recently logged areas, most often from lower elevations. Two things happened, however, to begin to raise concern about seed origins. First, silviculturists on the National Forests began to notice plantation failures. These failures often occurred many years after seemingly successful establishment, and often after infrequent, climatic insect or disease events. Adjacent, naturally regenerated stands did not fail. Second, trees from many of the seed sources in one of the early seed source studies, the 1912 Douglas-fir Heredity Study, were damaged and began to die after a particularly severe freeze in November of 1955. Concern over the loss of formerly productive stands gave rise to the first seed zones in Oregon and Washington with a map published in 1966.

Seed and breeding zones serve another function beyond the maintenance of adapted and productive forest stands. By restricting the environmental distance that plants may be moved from their native source, seed and breeding zones contribute to the conservation of genetic diversity and the maintenance of a species' geographic genetic structure. Localized seed collections serve an important role in gene conservation and ecological restoration. For example, a disjunct population of Douglas-fir on the Fremont National Forest was nearly completely consumed by the Silver Fire in 2002 (Stubbs 2003). Fortunately, recognizing the uniqueness of this population, seeds were collected some years earlier and may now be used to restore the population.

Methods to Explore Genetic Variation Structure in Forest Trees

Genetic variation may be found at the level of differences in: 1) DNA sequences; 2) simply inherited traits that are direct products of the expression of a single gene; or 3) quanti-tatively inherited traits that are controlled by several genes. Of greatest interest to the delineation of seed/breeding zones and seed transfer guidelines are traits related to adaptation, which are primarily quantitatively inherited traits. Genetic variation in these traits is revealed when trees from different families of different populations are grown together in the same environment, called common garden studies. Differences observed between populations are then most likely due to differences in genetics. Common garden studies may be long-term, including provenance and progeny tests, or they may be short-term, such as studies conducted in nursery beds or farm-field plots.

Long-term provenance studies test various seed sources at a range of planting locations. Because they are long term, provenance tests should provide the most reliable information on the health and productivity over the life of a stand. The long-time interval exposes the provenances to fluctuating climates, particularly to extreme climatic events. Provenance tests are also valuable for exposing provenances to biotic stresses to detect source-related variation in tolerance or resistance to pests (for example, Ying and Hunt 1987; Ying 1991; Ying and Liang 1994; Wu and Ying 1996). Provenance tests have proved particularly valuable as a general screen of source-related variation when introducing exotic species to new countries. The few provenance tests established in the Pacific Northwest have included too few and widely scattered sources (for example, Munger and Morris 1937; Squillace and Silen 1962; White and Ching 1985); although adaptive differences among provenances are evident, interpolation between sources is difficult. Provenance tests are expensive to establish, and finding sufficiently large test sites is difficult. The advantage of provenance tests—their long-term nature—is also a disadvantage; one must wait a long time to be confident in findings. Nevertheless, results from older provenance tests have demonstrated 2 key points: 1) the consequences of maladaptation often do not show up until many years into the life of the stand; and 2) it is the rare, extreme climatic events that are important in determining long-term survival. For example, in the Douglas-fir Heredity Study (Munger and Morris 1937), all seed sources performed relatively well for 4 decades. In November of 1955, the area had an unusual and prolonged cold spell (Duffield 1956), killing or severely damaging many of the offsite seed sources in the study, while the adjacent naturally regenerated stand suffered less damage and continued to grow well (Silen 2003).

Progeny tests also may serve the purpose of looking at geographic genetic variation. Progeny tests evaluate the parents of tree improvement programs for purposes of selection to rogue seed orchards or proceed to the next generation. The Pacific Northwest has hundreds of progeny tests of several conifer species, but most are Douglas-fir (Lipow and others 2002; Lipow and others 2003). The parents in these tests are usually well distributed, and information about the location of the parents is readily available. But parents in most first-generation breeding zones came from a limited geographic and elevational range; thus, extrapolation beyond the limited set of environments is difficult. Nevertheless, information from some of these tests has demonstrated clinal variation patterns in growth, phenology, and cold hardiness (Silen and Mandel 1983; Balduman and others 1999). Second-generation progeny tests of the NWTIC should allow a better evaluation of the potential for deploying improved genotypes over a wider area, since the parents tested for a given deployment zone come from a wider area than those in the first generation.

Short-term common garden studies in nurseries or farm-field tests are an alternative to longer term provenance and progeny tests. They have the advantage that many families and provenances may be grown in a relatively small area, usually at a location that is convenient for measuring a wide variety of traits. The environment within a test is usually very uniform, allowing less replication and better expression of genetic differences. The short-term nature and convenience of nursery common garden studies reduces the costs relative to long-term trials. The disadvantage of short-term tests is that they do not sample the range of climatic and biotic environments over the life of a stand, particularly extremes in climate. However, traits important for adaptation to climatic extremes (for example, growth, bud phenology, cold hardiness, drought hardiness) may be easily measured. Strong correlations of these traits to the physiographic and climatic variables of the seed-source locations is strong evidence that the traits have responded to selective pressures and are of adaptive importance. The inclusion of many well-distributed seed sources allows adaptive genetic variation to be mapped across physiographic space (Campbell 1986). The study of the relation between geographic genetic variation and environmental variation at a seed source has been termed "genecology" (Turesson 1923; Campbell 1979). The development of genecological studies using short-term common garden tests owes much to the pioneering work of Campbell in the Pacific Northwest (Campbell 1974b, 1979, 1986; Campbell and Sorensen 1978) and Rehfeldt in the Interior Western United States (Rehfeldt 1978, 1982, 1989).

Molecular markers consider genetic variation at the level of DNA, either as differences in the sequence of base pairs in DNA itself (for example, microsatellites, restriction fragment length polymorphisms, single-nucleotide polymorphisms), or as differences in gene products (for example, isozymes, terpenes). Molecular markers are generally considered to be neutral with respect to natural selection, that is, differences among markers are not indicative of adaptive differences among individuals or populations. For this reason, molecular markers are less valuable for delineating seed/breeding zones or seed transfer guidelines than quantitatively inherited adaptive traits. Differentiation among populations is generally much less for molecular markers compared to quantitative traits (Karhu and others 1996; Merilä and Crnokrak 2001; McKay and Latta 2002). Some studies have shown geographic patterns in marker variation, but they generally involve samples distributed over a very large range (for example, Li and Adams 1989; Lagercrantz and Ryman 1990) or markers that are associated with maternally inherited organelles that show limited dispersal (for example, Aagaard and others 1995; Latta and Mitton 1999). Neutral markers are most useful for distinguishing variation arising from nonselective evolutionary forces—migration (random movement of alleles among locations), genetic drift (random loss or fixation of alleles), or mutation (random change in the form of an allele). Future studies, however, hold promise for identifying genes that are controlling adaptive traits, and for exploring relations between variation in such genes and variation in quantitative traits identified in genecological studies.

Generalizations About Genetic Structure of Forest Trees

Temperate forest trees are predominately outcrossing with large amounts of gene flow due to widely distributed pollen and mostly continuous distributions. As a result, common garden studies have shown predominately clinal patterns of variation in which trait means change gradually in association with environmental variation (Figure 1). The patterns of variation, steepness of clines, and the strength of the association with the environment, however, differ greatly among species. Rehfeldt (1994) determined the environmental distances (differences in elevation and frost-free days) that were needed to detect differences among seed sources for several conifers in the Northern Rockies (Table 1). Species like Douglas-fir and lodgepole pine may be termed specialists. These species have populations that inhabit a relatively narrow niche; populations separated by only 200 to 220 m (660 to 720 ft) in elevation and 18 to 20 frost-free days may be considered genetically different. In contrast, populations of western redcedar and western white pine inhabit broad niches and show very little differences among populations over large environmental distances. These species may be termed generalists. Other species are intermediate between these extremes.

Patterns of genetic variation may differ among regions within a species' range. Western white pine shows very little geographic differentiation in the Northern Rockies, but a greater degree of differentiation along the Cascade Range in western Oregon and Washington (Rehfeldt 1979; Rehfeldt and others 1984; Campbell and Sugano 1989). In Douglas-fir, elevational clines in seedling size were much steeper in the Cascades than in the coastal mountains (Campbell and Sorensen 1978). In ponderosa pine, seedling size was more closely associated with differences in elevation east than west of the southern Oregon Cascades (Sorensen and others 2001), with an abrupt transition zone found at the Cascades crest (Figure 2). An abrupt change in a cline is referred to as a stepped cline, and is usually associated with secondary contact after historical separation between 2 differentiated races or taxa (Sorensen and others 2001).

Differences in genetic structure also exist among traits. In lodgepole pine in central Oregon, a set of traits associated with seedling size and vigor differed primarily with elevation, presumably in response to temperature, whereas a set of traits associated with seed and root size differed primarily with latitude and longitude, presumably in response to moisture availability (Sorensen 1992). In ponderosa pine in the Upper Colorado Basin, geographic clines in growth potential were northwest to southeast (at a constant elevation), whereas geographic clines in growth initiation varied more in an east-west direction (Rehfeldt 1990). Growth appeared to be related to temperature differences associated with latitude, whereas growth initiation appeared to be related to geographic patterns of spring and summer precipitation. Differences in geographic patterns among traits is expected, since different traits may be responding to different environmental factors, and the strength of selection may vary relative to the nonselective factors of migration and genetic drift.

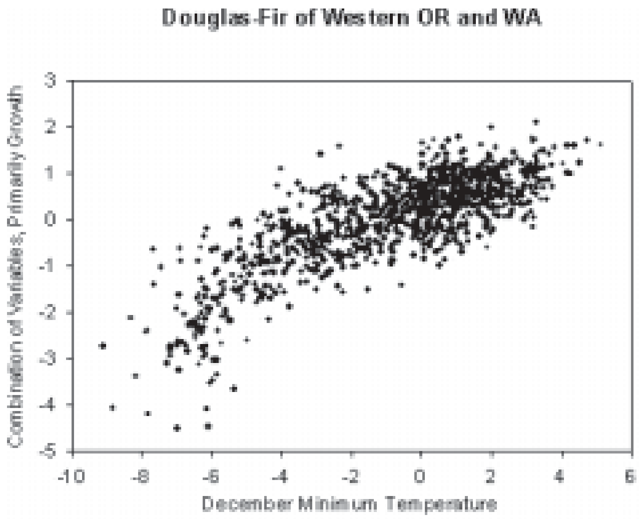

Figure 1—Graph of a composite trait representing growth vigor as related to December minimum temperature (°C) for Douglas-fir seed sources from western Oregon and Washington.

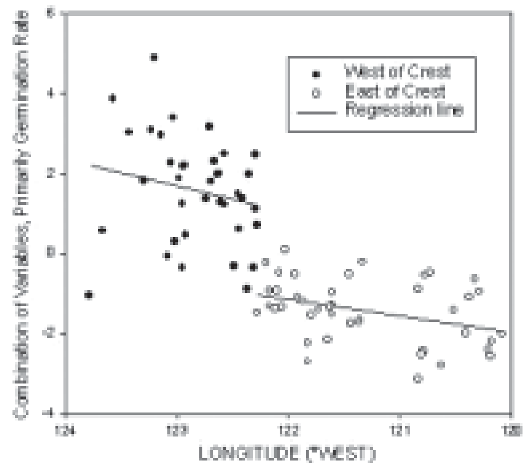

Figure 2—A stepped cline as illustrated in a graph of a composite trait, representing primarily germination rate, as related to longitude in a transect of ponderosa pine seed sources across the Cascades crest in southern Oregon.

Developing Seed and Breeding Zones or Transfer Guidelines

The first seed zones were developed in 1966 based primarily on differences in climate and vegetation. A slightly revised version was published a few years later (Tree Seed Zone Map 1973). The maps assumed that geographic differences in adaptive genetic variation were largely in response to past climates as reflected by the current climate and vegetation. These seed zones were fairly restrictive, both geographically and elevationally (Figure 3). Elevational transfers were restricted to zones of approximately 150 m (500 ft). The seed zones were the same for all species; it was not recognized at the time that species have different patterns of genetic variation.

Seed zones were recently revised for western Oregon and Washington to reflect current knowledge of geographic genetic variation based on genecological studies (Randall 1996; Randall and Berrang 2002). In most cases, seed zones were enlarged, particularly in a north-south direction (Figure 4). Species differences in geographic patterns of genetic variation were recognized in the new seed zones. Specialist species like Douglas-fir retained many seed zones with narrow elevational bands (Figure 4). Generalist species like western redcedar were given few seed zones with none to few wide elevational bands. Western redcedar may be moved large distances without concern for maladaptation, whereas Douglas-fir seed zones, although enlarged, are still relatively restricted. In a similar manner, Douglas-fir breeding zones used in NWTIC programs were enlarged between the first and second generation (Figure 5).

Seed zones are an administrative convenience for directing managers on how to bulk seeds from different stands for seed inventory purposes. But, as has been pointed out, genetic variation is continuous and predominately without discrete boundaries. Furthermore, similar genotypes may recur in similar environments in other seed zones, particularly as you move towards seed zone edges. For these reasons, seed transfer guidelines are more appropriate biologically. Campbell

Table 1—Environmental differences associated with genetic differentiation among populations of conifers in the Interior Western United States (from Rehfeldt 1994).

Species	Elevation difference to find genetic difference	Frost-free days to find genetic difference	Evolutionary mode
	m[a]		
Douglas-fir	200	18	Specialist
Lodgepole pine	220	20	Specialist
Engelmann spruce	370	33	Intermediate
Ponderosa pine	420	38	Intermediate
Western larch	450	40	Intermediate
Western redcedar	600	54	Generalist
Western white pine	none	90	Generalist

[a]1 m = 3.3 ft.

Figure 3—Original Washington tree seed zones.

Figure 4—Revised tree seed zones for western Oregon and Washington for (A) Douglas-fir and (B) western redcedar.

(1974a,b) laid the groundwork for the use of continuous models to estimate the effects of seed transfer. He later developed a method to quantify the relative risk of maladaptation from seed movement based on the amount of overlap between populations at 2 different environments (Campbell 1986). The amount of overlap is dependent upon the predicted means for a trait in the 2 environments as determined by regression models and the amounts of within population variation. Figure 6 presents a hypothetical example for transfers along an elevational gradient. Movement of a population from 500 to 600 m (1,640 to 1,970 ft) involves little risk as indicated by the considerable proportion of the populations in common at each location. Movement from 250 to 600 m (820 to 1,970 ft), however, could lead to considerable maladaption (greater risk) as indicated by the small amount of overlap between populations. Campbell's method provides a quantifiable estimate of risk of maladaptation for seed movements from a source environment to a planting environment. It is a relative risk and does not give an absolute proportion of a population that may not be expected to survive.

Monserud (1990) developed a rule-based expert system to guide seed transfer movement. This system is currently being used to guide seed movement of Douglas-fir, ponderosa pine, and western larch in the Northern Rockies (Mahalovich 2003). It uses models developed by Rehfeldt (for example, Rehfeldt 1990) to determine compatible seed sources for a given planting site.

Parker (1992) used geographic information systems software (GIS) to create a map of genetic variation in 2 sets of traits representing vigor and survival for jack pine in Ontario. Using GIS, he then mapped areas that were similar to what might be expected for a trait at a given point on the map. The mapped area, called a "focal point seed zone," indicates areas

Figure 5—Douglas-fir first- and second-generation Northwest Tree Improvement Cooperative breeding zones.

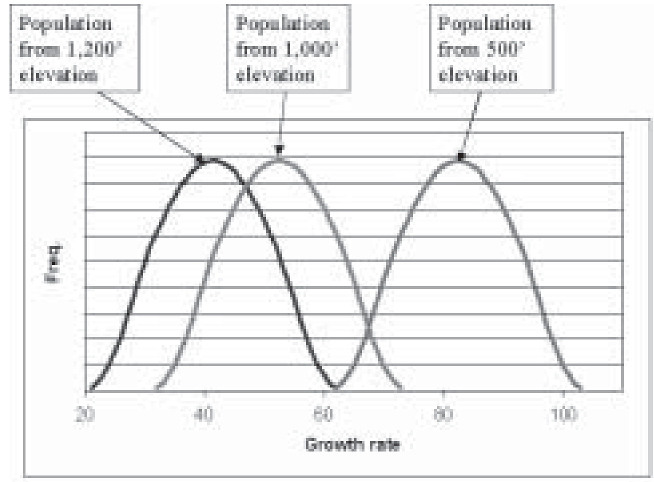

Figure 6—Hypothetical example illustrating seed transfer risks as the amount of overlap between populations from different elevations for a trait such as growth rate as evaluated in a common garden study (1 ft = 0.3 m).

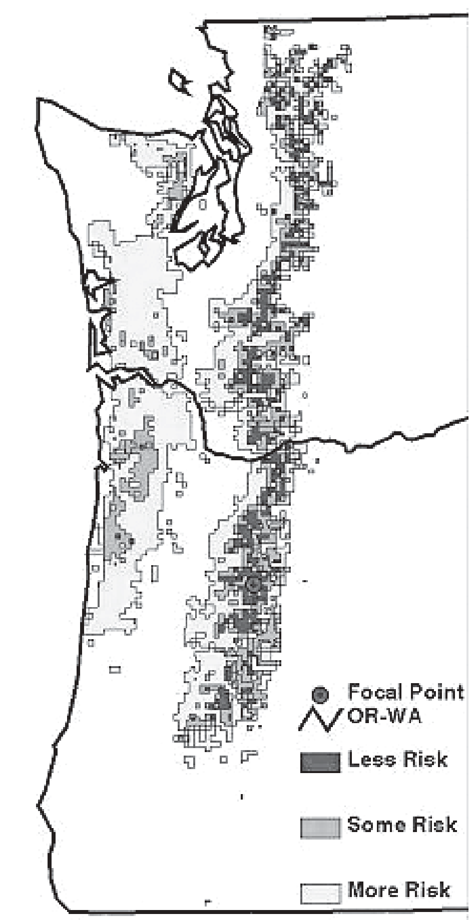

Figure 7—Focal point seed zone illustrating transfer risks for a focal point at mid-elevation in the Oregon Cascades.

that may be reforested with seeds from the given point with minimal risk of maladaptation, or, alternatively, areas where seeds from the given point may be used for reforestation. As an example, we show the focal point seed zone for a site in the central Oregon Cascades based on the results for geographic genetic variation in seedling vigor in a recent, unpublished genecological study of Douglas-fir (Figure 7).

Managers must decide at what level to bulk parents, whether they are using discrete seed zones or seed transfer guidelines. Ideally, one would bulk seeds from trees collected within a single stand at a specific location. Small geographic seed lots would allow greater flexibility for moving seeds to different planting environments and better knowledge of the risks involved. Keeping track of many small seed lots, however, is relatively expensive. For seed and seedling inventory purposes, bulking seeds at some higher spatial scale is desirable. Temperature appears to be a critical environmental factor for the adaptation of many tree species to their environments, and temperature is strongly affected by elevation, particularly within a seed zone. If parents are to be bulked at a finer scale than the elevation bands within seed zones, we recommend narrower elevation bands, and keeping track of those bands.

Summary

Moving plant materials has important consequences for the health, productivity, and diversity of forest ecosystems. Seed and breeding zones, and seed transfer guidelines, restrict the movement of plant material to minimize risks of maladaptation in plantations. Genetic structure determines the risk of maladaptation from seed movement; thus, knowledge of genetic structure is critical to delineating seed/breeding zones and developing seed transfer guidelines. Early seed zones assumed that genetic structure was largely reflected by geographic variation in climate and vegetation. They served their purpose well, but were rather conservative and did not consider species differences in genetic structure. Seed zones have been revised in the last decade to reflect current knowledge of genetic structure for each species. Revised seed zones are less restrictive, particularly for species with little geographic genetic variation. Managers face the issue of how large of an area to bulk parents into seed lots. They must evaluate the tradeoffs of the greater flexibility and better knowledge of risks of seed movement from using many small geographic seedlots versus the administrative ease and cost savings of using fewer large seedlots.

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Five Years of Irish Trials on Biostimulants—The Conversion of a Skeptic

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Abstract: Three biostimulants, Lysaplant (Bugico, Switzerland), Plantali (Vossen, The Netherlands), and Kerry Algae (Kerry Algae, Ireland), were tested over 5 years in Irish nurseries on a variety of conifer and broadleaf forest tree species. The trials were designed to test the following biostimulant claims: improved growth, disease protection in rooting cuttings, and reduced need for fertilizer.

Lysaplant seed coating was found to produce nearly a 2-fold increase of first order root length in 6-month-old Douglas-fir grown in nonfumigated soil. Lysaplant, Plantali, and Kerry Algae (foliar sprays), were used in growth experiments in the bareroot and container nurseries over 2 years on 10 species. Plantali and Lysaplant both increased height and diameter growth in most of the species tested, with some height increases greater than 20%. With the Lysaplant spray, fungicide use in the rooting of cuttings could be reduced to nearly zero with improved rooting (51% with fungicide, 68% with Lysaplant) under stressful rooting conditions. Lysaplant and Plantali were both effective in promoting growth even when the standard fertilizer rate was halved. Foliar analysis and visual color assessment indicated that the biostimulants improved N uptake.

The conclusion from this extensive series of trials is that Lysaplant and Plantali are biostimulants that work as insurance against the vagaries of the Irish weather conditions. These biostimulants improve growth and reduce fertilizer requirements. Lysaplant spray can be used to decrease the need for fungicide in the rooting of Sitka spruce cuttings while Lysaplant Root improves root morphology.

Keywords: reduced fertilizer, reduced fungicide, disease protection, growth improvement

Introduction

Ireland is a small country with an area of only 27,135 mi^2 (70,280 km^2). It is smaller than 40 of the 50 states in the US, and would rank in size between West Virginia and South Carolina. It has been under constant habitation by humans for at least 5000 years. During that time, much of the native species and the extensive prehistoric forests have been lost. Ireland is currently the least forested country in Europe with only 7% of the land forested. This is after 20 years of active government-funded afforestation!

Forestry plantations in Ireland would have a familiar feel to a forester from the Pacific Northwest. Many of the major conifer species have their origin in North America. For example, the major Irish conifer species are Sitka spruce, Japanese larch, hybrid larch, lodgepole pine, Scots pine, Norway spruce, and Douglas-fir, half of which are native to North America and none of which are native to Ireland.

Some native broadleaves are grown, but most of the plantations of these trees are not commercially viable because of their very slow growth rate. The most commonly grown broadleaves are pedunculate oak, sessile oak, European ash, and European beech.

There is very little natural regeneration in Ireland, so most of the stock for forest planting is grown in nurseries. Because the climate is similar to the Pacific Northwest and the species are the same, the growing regimes and the relative growth rates of the major species are quite similar. One of the major climatic differences, however, is that the winters are warmer and the summers are cooler in Ireland than in the Pacific Northwest. This means that the plants often grow faster in Ireland over a forest rotation than in their native habitat. However, a very cool, wet summer can have a negative effect on the growth in the nursery.

Over the years, we have tried various treatments to improve the consistency of nursery growth during variable years. We had little success until we began to test some sprays referred to as biostimulants. The term biostimulant is a bit of a catchall phrase. A biostimulant has been defined as a substance that is not a plant nutrient or pesticide but which in some manner has a positive impact on plant health. The biostimulant may enhance metabolism, increase chlorophyll efficiency and production, increase antioxidants, enhance nutrient availability, and increase the water holding capacity of the soil. With such an all encompassing definition, it is not surprising that almost anything that has a positive effect on growth under some circumstances, but has no obvious mode of action, has been lumped into the category of biostimulants. This has led to a wide variety of compounds and extracts of various things, from humus to algae, being classed as biostimulants. With this sort of “anything goes” definition, wild claims for various products have been made through the years, but vigorous research has often not corroborated the claims.

The objective of the studies outlined in this manuscript was to test the claims of 3 biostimulants on forest nursery species in Ireland. The 3 compounds were: 1) Lysaplant (Bugico, Switzerland), an extract of a number of organic compounds from specific sources (Table 1) that can be used both as a seed treatment and a foliar spray (Coates 1999); 2) Plantali (Vossen, Netherlands), an extract of the seaweed *Ascophyllum nodosum*; and 3) Kerry Algae, another seaweed extract produced in western Ireland. The claims tested are improved root morphology, disease protection with reduced fungicide use, improved growth under less than optimal conditions, and reduced need for fertilizer.

Materials and Methods

Study 1. Seed Coating with Lysaplant Root

Seeds of 5 species—hybrid larch (*Larix eurolepis*), Japanese larch (*Larix kaempferi*), Douglas-fir (*Pseudotsuga menziesii*), lodgepole pine (*Pinus contorta*), and Scots pine (*Pinus sylvestris*)—were mixed with Lysaplant Root prior to sowing at the recommended rate of 0.1 kg Lysaplant/kg moistened seeds (0.1 lb/lb). The larch and Douglas-fir were sown at Coillte’s Ballintemple Nursery at Ardattin in County Carlow, Ireland. The larch plots were replicated at Coillte’s Aughrim Nursery at Tinahely, County Wicklow, Ireland, where the pines were also sown. At both nurseries, the fields were treated with metam sodium as a soil fumigant. Treated seeds were sown in 3 nonadjacent nursery beds for each species. Surrounding beds were sown with nontreated seeds of the same seedlot and served as the control.

At the end of the first growing season, 50 plants were lifted from each of the treatments in each of the 3 blocks per species. Height and root collar diameter were measured, and a standard analysis of variance (ANOVA) was done.

Study 2. Rooting of Sitka Spruce (*Picea sitchensis*) Cuttings with Biostimulants and Reduced Fungicides

Two experiments were carried out to examine the effect of biostimulants on the rooting of Sitka spruce cuttings with reduced fungicides. Coillte grows Sitka spruce cuttings in raised beds filled with a mixture of 1:1:1 peat:perlite:bark in an unheated polytunnel. Cuttings are stuck in March, rooted, and then removed in September when they are transplanted to the bareroot nursery. They are then grown for a further year before planting in the forest.

In the first trial the plots were small, only 3 m^2 (32 ft^2). This was done so that a true control (no fungicide and no biostimulant) could be used. It was expected that the control would have a high level of infection with *Botrytis* spp., which commonly attacks cuttings in the humid environment. The treatments for this study were control, Lysaplant sprayed at a rate of 0.015 ml/m^2 every 3 weeks, and fungicide (a rotation of Captan, Benlate, Bravo®, and Rovral® sprayed at approximately 10-day intervals at recommended rates). The treatments were replicated randomly in each of 3 blocks that were widely spaced in the tunnel.

During the summer, a visual assessment was done every 2 weeks on the percentage of cuttings in a 10 by 10 block (100 cuttings sample) that had visible fungal infection on the needles in each treatment. In September, the cuttings were lifted. One hundred plants in each treatment per block were assessed. The number of plants with visible roots and the quality of the roots were assessed. The quality was on the following scale: no roots, less than 6 roots, more than 6 roots but not branching, more than 6 roots and fibrous. The last 2 categories were considered “good” root systems. Statistical analysis was carried out.

The second study was carried out in the subsequent year (2000) and was done on much larger plots (150 m^2 [1614 ft^2]) to confirm the results from the previous year. It consisted of the following 3 treatments: fungicide at full rate, fungicide at half the recommended rate with Lysaplant, and Lysaplant

Table 1—List of ingredients in Lysaplant (taken from the German patent DE 38 25 312 C2 29.05.91). Note: Lysaplant was formerly named Elorisan.

1. Aluminum nicotinate (natural source: *Nicotiana rustica* [Tobacco])
2. Sodium salicylate (natural source: *Filipendula ulmaria* [Meadow Sweet])
3. Anthraquinone (natural source: *Rheum palmatum* [Chinese Rhubarb])
4. Agininc acid silylester (natural source: *Laminaria digitata*)
5. Lithium carbonate
6. Urea/Saponine (natural source: *Carex arenaria* [Sedge])
7. Guanidinium nitrate (natural source: *Symphytum officiale* [Comfrey])
8. Potassium-o-ethyl dithiocardamate (natural source: *Carnellia sinensis* var. *assamica* [Green Tea])

alone. (Spraying the full rate of fungicide every 20 days with the full Lysaplant rate produced the fungicide at half rate with Lysaplant treatment.) The assessments were the same as in the first year. Cuttings were lifted in September and the percentage of plants rooted was determined. Statistical analysis was carried out.

Study 3. Effect of Different Algal Sprays on Growth of Bareroot Plants in the Nursery

Three crops were selected on which to try the algae sprays. Crops of 1+1 hybrid larch (*Larix eurolepis*), 2+0 lodgepole pine (*Pinus contorta*), and 1+0 sycamore (*Acer pseudoplatanus*) were treated with either Plantali or Kerry Algae at 3-week intervals over the summer to see if it improved growth. The Plantali was sprayed at a rate of 1 l/ha in 300 l water (0.1 gal/ac in 80 gal water). Plantali must be activated by beating the chemical into water. This was done using the supplied mixing tool on a drill. For the full rate, 500 ml (17 oz) of Plantali was added to 5 l (1.3 gal) of water and mixed for 5 minutes. This solution was then added to a sprayer and made up to 150 l (40 gal) for spraying on 0.5 ha (1.2 ac).

The Kerry Algae was also sprayed at the rate of 1 l/ha in 300 l water. Kerry Algae does not require activation, so was added directly to the sprayer and made up to 150 l to spray 0.5 ha.

Both chemicals were sprayed 6 times during the summer on the following dates: June 8, June 22, July 6, July 20, August 3, and August 17. An adjacent area of unsprayed plants was designated as a control. All normal fertilizer, herbicide, and protection sprays were used on the test areas.

Plants were lifted the following winter and measured for height and root collar diameter. Three replicates of 50 plants each were lifted and measured for each treatment by species combination for a total of 1350 plants. ANOVA was done on the data.

Study 4. Effect of Lysaplant and Plantali on the Growth of Seedlings in Containers in Two Very Different Seasons

Trials were conducted at Coillte's container facility at Clone, Aughrim, County Wicklow, Ireland during the summers of 1999 and 2000. Seeds were sown into 100 cc (6 in^3) containers in early spring each year. In 1999, the species used was European ash (*Fraxinus excelsior*); in 2000, pedunculate oak (*Quercus robur*), common birch (*Betula pubescens*) and common alder (*Alnus glutinosa*) were used. Plants were treated from mid-May to late September with Plantali at a rate of 0.1 ml/m^2 and Lysaplant at a rate of 0.015 ml/m^2 at roughly 3-week intervals. The Plantali was agitated as directed and both chemicals were applied using a backpack sprayer onto 1 pallet each (a pallet holds 1600 plants) in each of 3 blocks that were randomly located within the species. A neighbouring pallet to the treated pair was designated as a control in each block.

At the end of July 1999, and at the end of the growing season in October 2000, 40 plants from each treatment and block were measured for height and root collar diameter. ANOVA was done on the data.

Study 5. Growth of a Variety of Species and Stocktypes in a Bareroot Nursery Sprayed with Biostimulants

A pilot trial was conducted to examine the growth response of a number of species and stock types to treatment with biostimulants. At Coillte's Ballintemple Nursery the following species and stock-types were treated: 2+0 oak (*Quercus robur*), 2+0 ash (*Fraxinus excelsior*), 1+0 Japanese larch (*Larix kaempferi*), 2+1 Norway spruce (*Picea abies*), 2+1 Douglas-fir (*Pseudotsuga menziesii*), 1.5+0.5 Douglas-fir, transplanted July 7), 1+0 Norway spruce, and 1+0 birch (*Betula pubescens*). In Coillte's Aughrim Nursery, 2+0 oak was also treated.

The plots received the following treatments: Lysaplant sprayed at 100 ml/ha (1.4 oz/ac) and Plantali sprayed at 1 l/ha (0.1 gal/ac). Adjacent beds were designated as controls. Spraying began on June 6 and continued until mid-September at roughly 3-week intervals for a total of 8 sprays. The 1.5+0.5 Douglas-fir seedlings were only sprayed 5 times after transplanting on July 7.

At the end of the growing season, 3 samples of 50 plants each were lifted from the treatments and measured for height and root collar diameter. Statistical analysis was done on the data to compare the treatments.

Study 6. Effect of Biostimulants on the Fertilizer Requirement for Optimal Growth of 1.5+1.5 Sitka Spruce in the Final Year in the Nursery.

Sitka spruce (*Picea sitchensis*) were grown for 1.5 years in the seedbed and then transplanted at a spacing of 100 plants/m (30 plants/ft) in July of the second growing season. The biostimulant treatments were begun in the spring of the third growing season.

The biostimulants used were Lysaplant at the rate of 100 ml/ha and Plantali at 1 l/ha. The biostimulants were sprayed at roughly 3-week intervals from early May to mid-September for a total of 8 sprays. The control consisted of no biostimulant but all other treatments applied. Each biostimulant was sprayed in 5 nursery bed strips in each of 3 blocks, with a control of 5 beds in each block.

The nitrogen (N) fertilizer treatments were imposed over the biostimulant treatment. Each of the 3 middle beds of the 5-bed biostimulant plots was randomly assigned to 1 of the 3 levels of N fertilizer: full rate (best rate as determined in the nursery over many years), two-thirds of the full rate, and half of the full rate. The fertilizer was sulfa-calcium ammonium nitrate (S-CAN) ($26.5N:0P_2O_5:0K_2O:6.5Ca:5S$), a coated fertilizer that is neutral in pH effect and nonexplosive. Full rate was 600 kg/ha (536 lb/ac) S-CAN (160 kg/ha [143 lb/ac] N); two-thirds rate was 390 kg/ha (348 lb/ac) S-CAN (100 kg/ha [89 lb/ac] N), and half rate was 300 kg/ha (268 lb/ac) S-CAN (80 kg/ha [71 lb/ac] N). The fertilizer was applied in 6 equal applications from late April to mid-July.

The following winter, foliar samples were taken from the transplants for nutrient analysis. Samples of 50 trees were taken from each of the treatment plots in each of the 3 blocks for height and root collar diameter measurements.

Results of the foliar analysis were compared and morphological measurements were analysed using standard ANOVA procedures.

Results and Discussion

Study 1. Seed Coating with Lysaplant Root

The results of the study (Table 2) were very disappointing. Although there were some slight differences that were significant, they did not indicate that the Lysaplant had any positive effect on growth. Looking at the root systems of the larches and the Douglas-fir in some areas of the field, however, you could see a large positive difference in the root morphology with the Lysaplant. The areas where the better root systems were found corresponded to areas where the fumigation did not appear to have been successful (based on the rapid appearance of weeds).

We discussed our results with Dr. Derek Mitchell and Suzanne Monaghan, researchers at University College Dublin. They decided to study the effect of Lysaplant Root more thoroughly in the laboratory for Douglas-fir. Their results (Monaghan and Mitchell 1998) indicate that the root architecture of Douglas-fir is greatly affected by the Lysaplant in nonfumigated soil (Table 3). First order root length was nearly doubled. When a colleague of theirs tried the same experiment in sterilized soil, they found no effect (Monaghan 2000).

Lysaplant Root has a positive effect on the root growth of conifer seedlings in nonfumigated ground where it can act on the natural bacteria in the soil. Trials of Lysaplant root in containers in a peat-based media showed negative results (experimental data not reported) when a similar study was done on cherry (*Prunus avium*). It is believed that this is, again, due to the low level of microflora in the nearly sterile root environment.

Study 2. Rooting of Sitka Spruce (*Picea sitchensis*) Cuttings with Biostimulants and Reduced Fungicides

The results from the first study were encouraging. Disease incidence, as measured by the number of visible infections on the needles, was highest in the control at 11%. The visible incidence was only slightly less in the Lysaplant at 7% (Table 4). Remarkably, the incidence of disease did not correspond to the rooting percentage. All the treatments rooted at a significantly higher percentage than the control with no significant difference between the treatments (Table 5). This would indicate that Lysaplant was as effective as the fungicide in controlling the disease problems and rooting. The year of this study (1999) was cool and wet. These are good conditions for rooting and the 80% rooting in this study reflected this.

Table 2—Comparison of growth of 1 + 0 seedlings after seed treatment with Lysaplant Root at 2 nurseries. Pairs of numbers followed by * are significantly different at the *P* = 0.05 level.

Species	Test	Ballintemple Nursery Height	Ballintemple Nursery Diameter	Aughrim Nursery Height	Aughrim Nursery Diameter
		cm	*mm*	*cm*	*mm*
Japanese larch	Control	8.9	1.4	11.0	1.7
	Lysaplant	9.1	1.4	11.0	1.7
Hybrid larch	Control	9.3	1.6*	13.8	1.9*
	Lysaplant	10.3	1.9*	12.7	1.6*
Douglas-fir	Control	12.7	1.8		
	Lysaplant	10.6	1.6		
Scots pine	Control			6.9*	2.4
	Lysaplant			6.4*	2.5
Lodgepole pine	Control			7.3	2.3
	Lysaplant			6.7	2.1

Table 3—Morphometric measurement (mean ± SEM) of the root systems of 6-month-old Douglas-fir seedlings (from Monaghan and Mitchell 1998).

	Lysaplant Root—treated	Control
First order root length (cm)	4.5 ± 0.6	2.5 ± 0.4[a]
Main root diameter (mm)	1.03 ± 0.03	0.73 ± 0.02[b]
First order root diameter (mm)	0.64 ± 0.03	0.48 ± 0.07[b]

[a] and [b] denote significantly different at 1% and 5% level respectively using Student's t-test.

Table 4—Visual assessment of *Botrytis* spp. on the needles of Sitka spruce cuttings given treatments as noted throughout the summer.

Treatments	Disease	Dead needles
	- - - - - - *percent* - - - - - -	
Control	11	22
Lysaplant	7	19
Fungicide	2	16

Table 5—Final rooting percentage and the percentage of good roots for Sitka spruce cuttings. Treatments followed by the same letter in a column do not differ significantly at the *P* = 0.05 level.

Treatments	Rooted	Good roots
	- - - - - - *percent* - - - - - -	
Control	57 a	43 a
Lysaplant	80 b	63 b
Fungicide	81 b	61 b

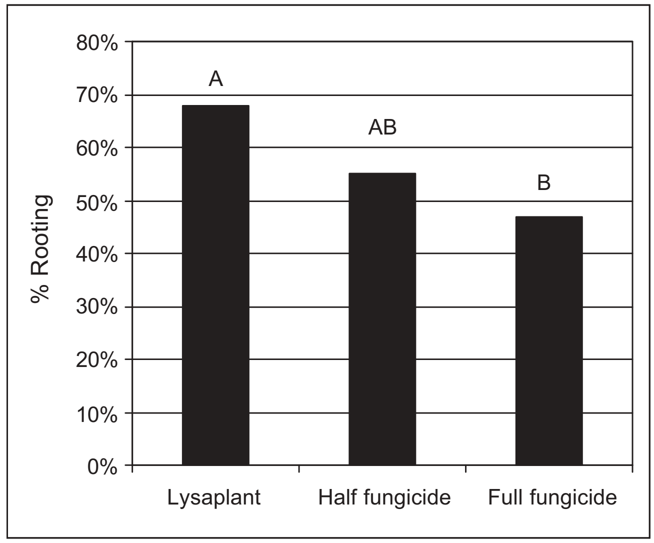

Figure 1—Rooting of Sitka spruce in a poor rooting year sprayed with full rate (1X/wk) fungicide, half fungicide rate (1X/2 wk), and Lysaplant only. Bars that have the same letter above them do not differ significantly at the *P* = 0.05 level.

In 2000 (a warm, sunny summer), rooting was reduced probably because of excessive heat in the tunnels. Under these conditions of stress, the Lysaplant improved the rooting by 17% over the standard fungicide treatment, from 51% to 68% (Figure 1). Only one spot spray of fungicide was needed to control disease in the Lysaplant treatment.

Study 3. Effect of Different Algal Sprays on Growth of Bareroot Plants in the Nursery

The lodgepole pine, hybrid larch, and sycamore all showed a similar response to the biostimulants applied (Table 6). Kerry Algae had no significant effect on the growth of any of the species tested. Plantali, on the other hand, worked on all the species tested to increase growth an average of approximately 10% for both height and diameter growth. After these poor results, no further trials were done with Kerry Algae.

Study 4. Effect of Lysaplant and Plantali on the Growth of Seedlings in Containers in 2 Very Different Seasons

The summer of 1999 was cold and wet. Growth was below average, even in the greenhouse. In that year, the results of the biostimulants on the growth of the ash were very impressive, with both sprays showing greater than 30% increase in height growth (Table 7). In contrast, 2000 was a much better growing season. Plants in the containers grew very tall and were probably restricted by the volume of the container. The growth of all 3 species was completely unaffected by the biostimulants (Table 8, only height data shown).

Study 5. Growth of a Variety of Species and Stocktypes in a Bareroot Nursery Sprayed with Biostimulants

Biostimulants increased growth in most of the species and age classes tested. The results, however, were not entirely consistent (Table 9). In the 2+0 oak at 1 nursery, the growth nearly doubled with biostimulant spray; there was little difference in growth at the other nursery. At the nursery where the difference was pronounced, the plants were not fertilized as intended because of heavy rains after applications, and the plants suffered from mildew. Under these conditions, the biostimulants greatly promoted growth.

The 1+0 birch showed a good response to the biostimulant; the 2+0 ash showed little effect.

All the conifers tested, with the exception of the 1+0 Norway spruce, showed an improvement in height growth and diameter growth with biostimulant spray. There is little difference between the 2 types of biostimulants in the response. The 2+1 Douglas-fir appeared most responsive, with a 12% increase in height and a 7% increase in seedlings transplanted in June and sprayed twice.

The most impressive results were from the treatment of the Japanese larch, where the plants went from a size that was not large enough to transplant without the biostimulant to a size suitable for transplanting after treatment—an increase in height of 39%.

Table 6—The effect of spraying 2 biostimulant algae preparations for 1 growing season on the growth of 3 species in the nursery. All numbers in a column followed by the same letter are not significantly different at the *P* = 0.05 level. NS = not significant.

Treatment	2+0 lodgepole pine Height	2+0 lodgepole pine Diameter	1+1 hybrid larch Height	1+1 hybrid larch Diameter	1+0 sycamore Height	1+0 sycamore Diameter
	cm	*mm*	*cm*	*mm*	*cm*	*mm*
Control	12.7 a	2.9 a	42.9 a	6.3 ns	13.9 a	4.0 a
Kerry Algae	12.3 a	2.7 a	42.7 a	6.4	14.5 a	3.8 a
Plantali	14.8 b	3.2 b	46.3 b	6.5	15.5 b	4.4 b
(% increase over control)	(+16.5)	(+10.3)	(+7.9)		(+11.5)	(+10.0)

Table 7—The effect of biostimulatants on the 2-month growth of ash seedlings in a poor year (1999). Means followed by the same letter within a column do not differ significantly at the *P* = 0.05 level.

Treatment	Height	Improvement	Diameter	Improvement
	cm	*percent*	*mm*	*percent*
Plantali	18.3 b	42	4.2 b	14
Lysaplant	17.1 b	33	3.9 a	5
Control	12.9 a	—	3.7 a	—

Table 8—Effect of biostimulants on the height growth of 3 species grown in containers in a very good growing season. None of the differences are significant.

Treatment	Oak	Birch	Alder
	- - - - - - - - *cm*	- - - - - - - -	
Lysaplant	39	60	69
Plantali	40	60	69
Control	39	61	72

Study 6. Effect of Biostimulants on the Fertilizer Requirement for Optimal Growth of 1.5+1.5 Sitka Spruce in the Final Year in the Nursery

During the growing season, color differences were noted in the control treatments, with the reduced fertilizer levels appearing very yellow in the field. Lysaplant treated trees remained green at all levels of fertilization. Plantali treated trees were greener at the full and two-thirds rate, but appeared yellow at the half rate.

These visual observations were supported by the foliar analysis results (Table 10). Note that the decrease in foliar N level with decreasing fertilizer was much less pronounced in the biostimulant treatments than the control (Figure 2).

Growth was affected by the biostimulant x fertilizer interactions. In Figure 3, it can be seen that the Lysaplant treatment resulted in greater growth than the control at both two-thirds and half fertilizer rate. Although not statistically significant, Plantali treated plants appear to have grown better at all the fertilizer rates than the controls. As expected, the growth of the untreated plants was lower at the lowest fertilizer rates.

Conclusions

After this extensive series of experiments, what conclusions can we make about biostimulants? The first conclusion is that not all biostimulants are created equal. Kerry Algae did not work in any of the trials in which it was tested. (Only one trial was reported here; others were undertaken.) Plantali and Lysaplant both gave very good results in most of the trials. Biostimulants appear to work best when the plants are under some kind of stress, either environmental from poor growing conditions, disease, or reduced fertilizer (Blake 2002). They do not improve growth when all the factors are optimal, but act more as an insurance policy to protect the nursery against the vagaries of nature.

In this series of trials, we set out to examine 4 claims of the biostimulants. The first was to determine if Lysaplant Root (a seed pre-sowing treatment) could affect the root architecture of poor rooting species by acting on the bioflora in the soil. Although our initial trial was unsuccessful in fumigated soil, when the trial was repeated in nonfumigated soil in laboratory conditions, it was found that the number of roots and branching of the root system was greatly increased in Douglas-fir. This claim was thus substantiated. For species such as Douglas-fir and hybrid larch, where root systems are often not well developed when the plants are sent to the field, this level of improvement in root morphology may play a significant role in improving outplanting success.

The second claim that we set out to test in the nursery was that Lysaplant spray could protect plants from disease attack. The manufacturers claim that the spray induces changes in the leaf membranes that make it more difficult for fungi to attack the plant. The only situation in the

Table 9—Results of biostimulant sprays in 2000 on the height (cm) and diameter (mm) of a variety of species and age classes. Means followed by the same letter within a row do not differ significantly at the $P = 0.05$ level.

Size measurements species-plot (age)	Measure	Lysaplant	Plantali	Control
2+0 Oak Aughrim	Height	72.5 b	70.4 b	49.6 a
	Diameter	10.7 b	9.6 a	9.3 a
2+0 Oak	Height	70.5	75.3	75.2
	Diameter	10.1 a	11.0 b	11.2 b
1+0 Birch	Height	23.2 b	22.2 b	17.4 a
	Diameter	3.9 a	4.4 b	4.5 b
2+0 Ash	Height	39.5	40.5	40.4
	Diameter	11.1 b	10.8 a	11.5 b
1+0 Japanese larch	Height	7.4 c	6.4 b	5.3 a
	Diameter	2.1 b	1.8 a	1.7 a
2+1 Norway spruce	Height	17.9 b	18.2 b	14.0 a
	Diameter	4.7 b	4.6 b	3.7 a
1+0 Norway spruce	Height	5.2	5.3	5.4
	Diameter	0.9 a	1.0 b	1.1 b
2+1 Douglas- fir	Height	43.3 b	43.3 b	38.6 a
	Diameter	8.6 b	9.2 c	7.1 a
2+0[a] Douglas-fir	Height	23.1 b	22.8 b	21.6 a
	Diameter	3.6 b	3.6 b	3.3 a

[a]Treated after transplanting in June until the end of the growing season.

Table 10—Foliar analysis of Sitka spruce transplants after 1 year of biostimulant treatments at varying fertilizer levels.

Biostimulant	Fert.	Na	P	K	Ca	Mg	Cu	Zn	Fe	Mn	B
		percent					*ppm*				
Control	Full	2.06	0.28	1.21	0.67	0.17	4	53	110	87	18
	Two-thirds	1.67[a]	0.30	1.23	0.70	0.16	4	55	116	67	11
	Half	1.63[a]	0.27	1.25	0.64	0.15	3	37	78	57	15
Lysaplant	Full	1.89	0.38	1.45	0.86	0.18	4	75	104	174	23
	Two-thirds	1.87	0.37	1.47	0.84	0.18	5	72	84	163	21
	Half	1.82	0.35	1.51	0.77	0.18	4	65	82	144	22
Plantali	Full	2.03	0.32	1.34	0.80	0.18	5	55	110	73	21
	Two-thirds	1.92	0.38	1.59	0.84	0.17	4	73	88	113	22
	Half	1.78	0.34	1.41	0.76	0.15	4	56	100	78	21

[a] N levels are below our recommended foliar N content (1.75%) for plants going to the field.

nursery where we predictably get disease attack every year is in the rooting of Sitka spruce cuttings. Because the cuttings are rooted under mist in low light levels for up to 3 months, disease is prevalent.

For 2 years, we tested the Lysaplant against our standard fungicide regime for protecting the cuttings from attack by *Botrytis* spp. In each year, the Lysaplant worked as well as the fungicide in reducing fungal attack. In a poor rooting year, it significantly improved rooting. Coillte's rooting tunnels have used Lysaplant as part of the standard regime for the last 3 rooting seasons with excellent results and an 80% reduction in fungicide usage. Only an initial overall spray of fungicide is given just after the cuttings are stuck to reduce the spore population, and small areas are spot sprayed if *Botrytis* patches are discovered.

With new regulations reducing the range of fungicides available to the nursery, products that help to stimulate the plant to protect itself may be the direction for the future. Further tests need to be conducted to see if Lysaplant can protect forest nursery plants against other common nursery diseases.

The third claim tested in the nursery was that biostimulants improved growth. This is the easiest claim to test, and all 3 biostimulants under consideration were tested. A variety of species and stock types were examined, both bareroot and container. Results were generally good with

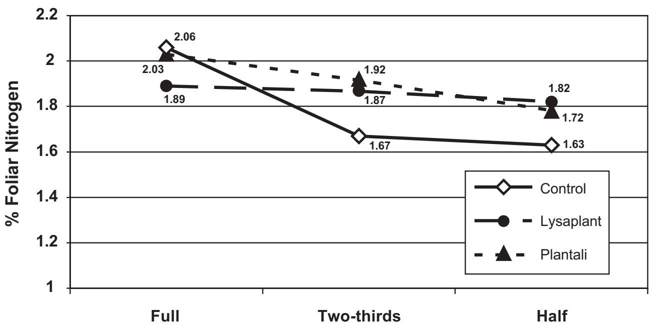

Figure 2—Effect of decreasing N application (full rate = 160 kg/ha N, two-thirds rate = 100 kg/ha N, and half rate = 80 kg/ha N) on the foliar N level of Sitka spruce at the end of the growing season.

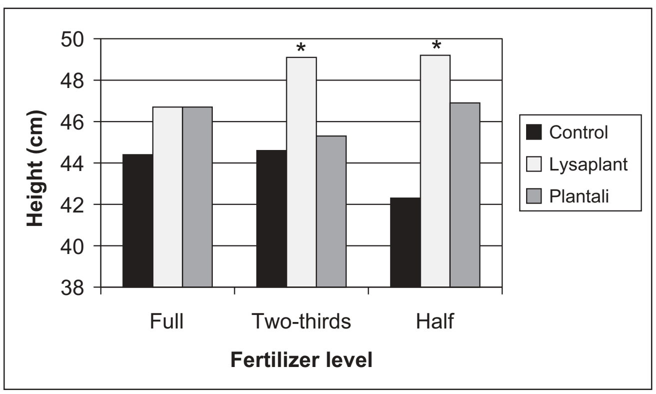

Figure 3—Interaction between fertilization level and biostimulant spray. Bars marked with * differ significantly at the $P = 0.05$ level from the control at full fertilizer rate.

Lysaplant and Plantali, while there was no effect with Kerry Algae. Some spectacular results were noted, with a 42% increase in height in container ash with Plantali and 46% increase in 2+0 oak height with Lysaplant where oak mildew affected the growth of the controls. The results, however, are not consistent. Where the growth of the controls was very good, the biostimulants did not improve it. For growth particularly, Lysaplant and Plantali act as an insurance policy against something else in the growing environment restricting growth.

The final claim tested was that, with biostimulants, the amount of fertilizer (N) needed to grow crops could be reduced significantly. This was the assertion that was the most difficult to believe. With the Lysaplant being sprayed at a mere 100 ml/ha (5 to 7 times per season), the claim that fertilizer could be reduced by up to 50% (80 kg/ha N) seemed very farfetched. In fact, the Lysaplant manufacturers maintain that high levels of N actually reduce the effectiveness of their product. In our controlled experiments with Lysaplant and Plantali, we found that their claims were indeed substantiated. While the growth and N content of the control 2+1 Sitka spruce was less with decreasing fertilizer, Plantali treatments showed little effect and seedlings treated with Lysaplant grew significantly better with decreasing fertilizer. In this era of increased awareness of water quality and N pollution, the fact that the fertilizer can be halved without decreasing growth with the use of biostimulants must be a welcome finding and should have important consequences.

Finally a personal note: I entitled this paper the "conversion of a skeptic" and I must admit that I began this series of studies under protest. When I was presented with the biostimulants and began to read up on the literature, I found many wild claims but very little good data or substantiation of the claims. This series of trials was started because of a request from a government official who wanted data on Kerry Algae, the Irish product. I decided that if we were going to test 1 biostimulant, we ought to test some that were considered successful in other countries. Plantali was chosen because it and its related product, Herbali, are used extensively in the nurseries in Holland. The Lysaplant was selected on the recommendation of a Danish grower who claimed good success with it.

I fully believed that the first study would be the last and we could say that none of this stuff works. Life isn't that simple. Some of the first studies had spectacular results. There was really something positive going on here. After 5 years and more studies than those reported here, I have to say I am now a believer. I still don't know how a compound that is used at such a low concentration can have such a large effect, but I'm now convinced it does.

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Propagating Plant Materials for the Hopi Reservation, Arizona

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Abstract: The USDA Forest Service, USDA Natural Resources Conservation Service (NRCS), and the Hopi Tribe Office of Range Management are collaborating on a plant materials project for Hopi wetland and riparian areas. The objective of the project is to generate seedlings rather than rooted cuttings of native willows, cottonwoods, and aspen to restore and maintain the genetic diversity of the isolated wetland and riparian populations. In addition to their value in ecological restoration, these plants also hold cultural significance to the Hopi Tribe. Plant materials were collected on the Hopi Reservation for propagation and generation of seeds and seedlings at the NRCS Plant Materials Center in Los Lunas, New Mexico. Major species collected include cottonwood (*Populus fremontii* and *P. acuminata*), aspen (*Populus tremuloides*), and willows (*Salix gooddingii, S. exigua,* and *S. lutea*).

Keywords: restoration, culturally significant plants, invasive species, Intertribal Nursery Council, *Salix* spp., *Populus* spp.

Introduction

The Hopi Reservation is 1.6 million ac (650,000 ha) in size, and is located in northeast Arizona (Figure 1). This plant materials project was conceived at the first meeting of the Intertribal Nursery Council in Durango, Colorado in August 2001. Max Taylor and Priscilla Pavatea of the Hopi tribe asked for help in propagating plant materials for riparian and restoration projects on the Reservation. The tribe has been working to eradicate the exotic plants tamarisk (*Tamarix ramosissima* Deneb.) and Russian-olive (*Elaeagnus angustifolia* L.), which have taken over many of the streams and springs on the Reservation. Although these areas only comprise about 2% of the Reservation, they are ecologically and culturally valuable for livestock grazing, wildlife habitat, traditional gathering, and ceremonial use (Lomadafkie 2003).

Because "nature abhors a vacuum," we proposed growing native willows, cottonwoods, and aspen to outplant in the project areas once the exotics have been removed. One of the unique aspects of this restoration project is that, because these species are dioecious, our target plant material will be seedlings, not cuttings, to restore and maintain genetic diversity (Landis and others 2003). Another challenge is that some of the wetland and riparian areas are so isolated on the Hopi Reservation that the some of the existing plant stands are comprised of plants of only one sex (Figure 2A), and sometimes only one individual (Figure 2B). Therefore, our project objective was to produce seedling plant materials that will survive and grow into sustainable plant communities.

The Propagation Plan

The first step in our propagation plan (Table 1) involved identifying and collecting mature male and female hardwood cuttings from riparian and wetlands project areas on the Hopi Reservation (Figure 1). The sex of the cottonwoods was confirmed by dissecting and examining the sexual buds. Because the willow buds were smaller, we made tentative identifications by looking for dried-up flowers or capsules. The cuttings were taken back to the NRCS Los Lunas Plant Materials Center in Los Lunas, New Mexico, where they were rooted. Once established, the rooted cuttings will be forced to flower, cross-pollinate with

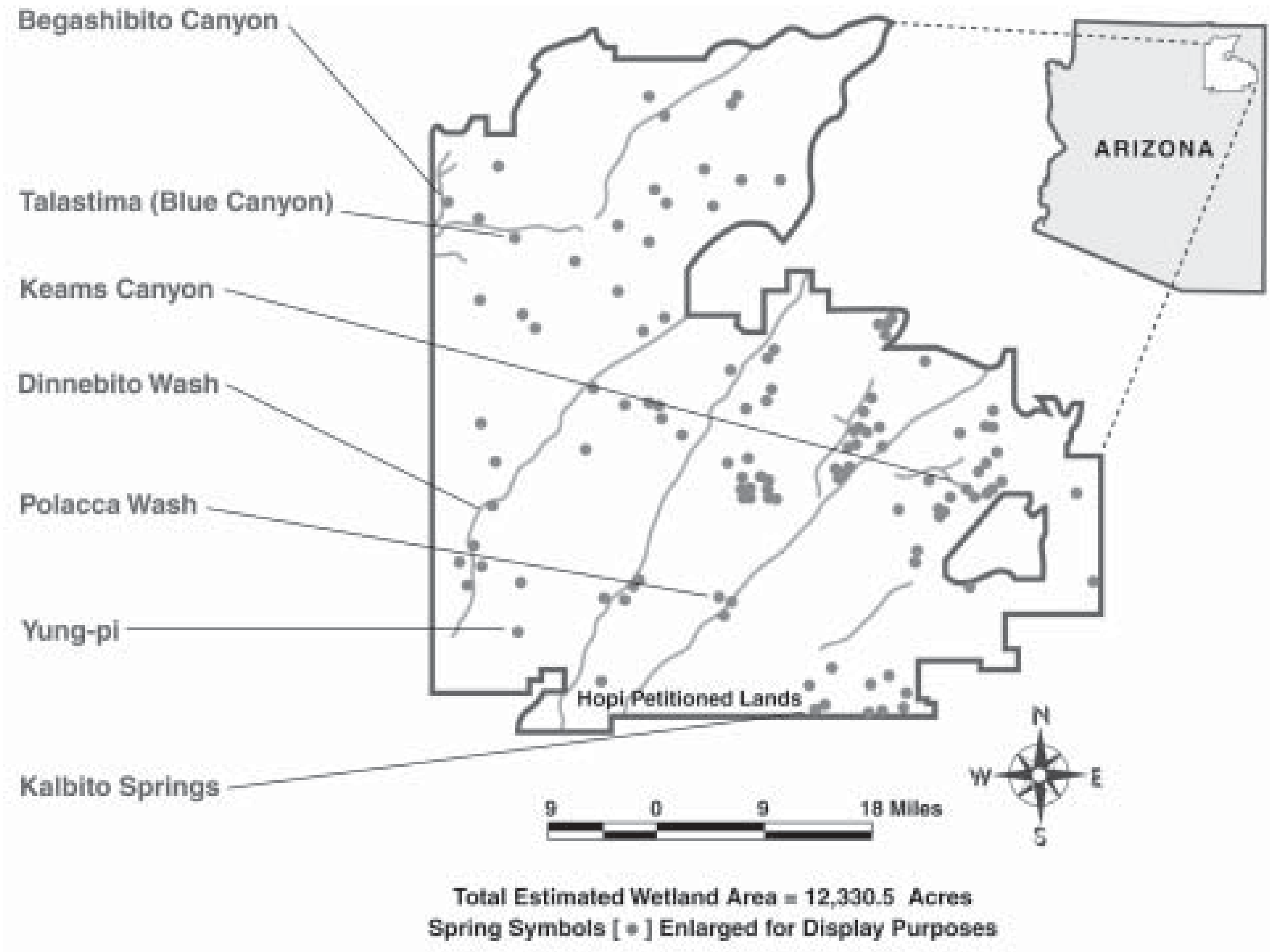

Figure 1—Map of riparian and wetland restoration projects on the Hopi Reservation, Arizona.

plants from different project areas, and produce seeds. These genetically diverse seeds will be collected, processed, and sown to produce seedlings. This entire process of propagating genetically diverse seedlings will take up to 4 years (Table 1). In addition, some of the rooted cuttings of cottonwoods and the tree-type willows will be grown into poles for outplanting on the project site.

Because of their rarity on the Reservation and the fact that stem cuttings will not root, the propagation of quaking aspen (*Populus tremuloides*) presented a special challenge. Therefore, sections of root suckers were collected and taken to Los Lunas where propagation was attempted (Dreesen and others 2002).

During field collections, it was noticed that some stands appeared to all be of the same sex. Therefore, leaves were collected for genetic testing at the USDA Forest Service National Forest Genetic Electrophoresis Laboratory (NFGEL) in Placerville, California.

Collecting Plant Materials

We collected plant materials during 3 separate periods in 2003.

Mid-January 2003

We collected dormant hardwood cuttings of *Populus fremontii* (Fremont cottonwood), *Salix exigua* (coyote willow), *S. gooddingii* (Goodding's willow), and *S. lutea* (yellow willow) in Keams Canyon, Blue Canyon, and Blue Bird Springs (Figure 1). Cuttings were taken from the upper branches with a pole pruner to ensure collection of mature cuttings with floral buds. We identified *Populus* sex by cutting the floral buds with a razor blade and examining them with a hand lens. With magnification, round pistils could be identified in the cross section of the female floral buds. After several plants were sampled, it was determined that there was a trend in floral bud shape to the sex of Fremont cottonwood. The female buds were determined to be smaller and rounder, while the male floral buds were larger and pointed. It was not as easy to decipher the sex in the *Salix* spp.; the buds were too small to make a field determination. Instead, *Salix* sex was determined by the presence of dried leftover flowers from the previous spring. When there was absolutely no indication of sex, random samples were taken from multiple plants in an attempt to capture as many male and female source plants as possible. For both species, individuals were labeled with location,

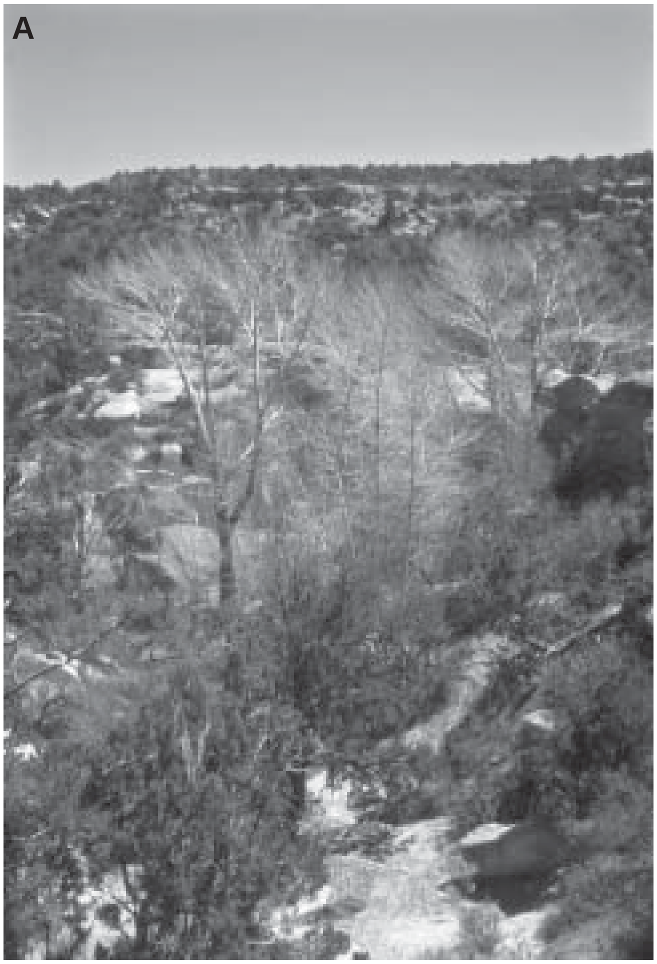

Figure 2—On the Hopi Reservation, many willow, cottonwood and quaking aspen stands are extremely isolated and therefore genetically and sexually limited. A) A stand of lanceleaf cottonwood was found to consist of single clones, all male. B) Max's aspen appears to be a single individual that is severely browsed.

including latitude and longitude, bagged in plastic bags separately, and marked male or female when possible. All plant materials were then taken to the NRCS PMC in Los Lunas for rooting and nursery culture.

Mid-April 2003

We made a second collection of hardwood cuttings in Keams Canyon, Deer Springs, White Ruin Canyon, Lamb Well, Aspen Canyon, and Max's Aspen seep. During this time, we collected *Salix goodingii*, *Populus acuminata* (lanceleaf cottonwood), and *P. tremuloides*. Our procedure was the same as that used in the first collection, except for collection of the aspen. For aspen, shovels, pulaskis, and clippers were used to gather root suckers approximately 2 cm (0.75 in) to 3 cm (1.25 in) in diameter, and 30 to 60 cm (1 to 2 ft) in length. Plant materials were handled, labeled, and transported in the same manner as the first collection.

Table 1—Propagation strategy for collecting and propagating willows, cottonwoods, and aspen on the Hopi Reservation, Arizona.

Propagation plan	Where	When	What
Step 1	Project sites (Figure 1)	Years 1 and 2	1. Identify sex of donor plants 2. Collect mature hardwood cuttings 3. Collect seeds whenever possible
Step 2	Nursery	Years 1 and 2	1. Root cuttings 2. Force flowering and promote pollination 3. Collect and clean seeds
Step 3	Nursery	Years 1 and 2	1. Sow seeds into miniplug containers 2. Grow seedlings large enough to transplant
Step 4	Nursery	Years 1 and 2	1. Transplant miniplug seedlings into large containers 2. Grow to shippable size
Step 5	Project sites	Year 2 and on	Outplant willow, cottonwood, and aspen seedlings of diverse genetic origins and both sexes
Step 6	Project sites	Ongoing	Outplanted stock flowers and pollinates with existing plants to produce genetically diverse seed

Mid-May 2003

A third collection of plant materials was done on the Hopi Reservation at Keams Canyon, Blue Canyon, Blue Bird Springs, Deer Springs, and Aspen Canyon. To increase the genetic diversity in our samples, an additional collection of aspen root sections was made at Washington Pass on the Navajo Reservation with the permission of the Navajo Department of Forestry.

In addition to the branch and root cuttings, we also collected leaf samples for genetic testing of cottonwood and willows because we suspected that some stands could be comprised of a single clone. Leaf sample collection was done according to the NFGEL *General Collection Guide for Vegetative Materials*. Ten random samples of *Populus acuminata* were taken from Deer Springs, 9 random samples of *Salix goodingii* were taken from Blue Canyon, and 10 random samples of *Salix lutea* were taken from Blue Bird Springs. Samples were processed at NFGEL.

Results and Discussion

Willows and Cottonwoods

The cuttings from all collections have been cultured at the Los Lunas Plant Material Center to produce seedlings for Hopi lands restoration plant materials. Seedlings are to be outplanted in the fall and spring after 3 years of culturing (Table 1). Protocols have been developed by NRCS Horticulturist Dave Dreesen for producing seedlings from rooted cuttings and/or seeds (Dreesen 2003). The process involves the collection of dormant cuttings with floral buds from male and female *Salix* species. These cuttings are rooted and forced to flower in the nursery. Flowers are pollinated, and seeds are collected for production of restoration project seedlings. The seedlings are grown and transplanted until the target plant material is reached.

At the end of the first growing season, 5 species of willows and 2 species of cottonwood had been propagated as rooted cuttings (Table 2). Some of these can be outplanted this fall but most will be kept in the nursery so that they can flower and cross-pollinate next spring. The resultant seeds will be collected, processed, and sown immediately to produce genetically and sexually diverse seedlings. Note that 2 new species of willows were identified after the cuttings had rooted and produced leaves. We will have to wait until next spring to identify the sex of these collections.

In the field, all of our collected yellow willow cuttings were female, and all the lanceleaf cottonwood cuttings were male. Not only were they the same sex, but the preliminary results of the genetic testing done at NFGEL confirm our field observations that the lanceleaf cottonwood (Figure 2A) and the yellow willow samples are each from one clone (Hipkins 2003). These tests confirm our initial assumption that the extreme isolation of some of the project sites has resulted in clones that are genetically and sexually identical. We hope to be able to locate other individuals of the opposite sex so that we can cross-pollinate and produce seeds of greater diversity.

Table 2—Rooted cuttings produced in first year at Los Lunas Plant Materials Center, New Mexico.

			Inventory	
Plant species	Project site	Sex of plant	Original cuttings (stuck spring 2003)	Rooted cuttings available for outplanting (fall 2003)
Goodding's Willow	Keams Canyon	Male	80	20
Goodding's Willow	Blue Canyon	Male?	214	110
Goodding's Willow	Blue Canyon	Male	266	200
Goodding's X Peachleaf Willow [a]	Keams Canyon	Female	98	70
Coyote Willow	Blue Canyon	Male	61	0
Coyote Willow	Blue Canyon	Male	187	160
Coyote Willow	Blue Canyon	Female	154	135
Coyote Willow	Keams Canyon	Unknown	98	70
Yellow Willow [b]	Bluebird Springs	Female	235	140
Pacific Willow [a]	Keams Canyon	Female	161	110
Fremont Cottonwood	Keams Canyon	Female	38	10
Fremont Cottonwood	Keams Canyon	Male	45	15
Fremont Cottonwood	Keams Canyon	Male	43	10
Fremont Cottonwood	Keams Canyon	Female	67	0
Fremont Cottonwood	Keams Canyon	Female	56	10
Fremont Cottonwood	Blue Canyon	Female	119	30
Fremont Cottonwood	Blue Canyon	Male	52	0
Lanceleaf Cottonwood [b]	Deer Springs	Male	231	120

[a] New species identified after rooting cuttings.
[b] Single sex clones.

Quaking Aspen

Our initial propagation trials with root cuttings of quaking aspen were not successful. This may be due to the timing of the collections. Therefore, we will try to collect root sections earlier in the winter. Aspen catkins were collected in Aspen Canyon on the Hopi Reservation but yielded no viable seeds. This may have been due to the extreme drought. Next spring we will try to collect branches with female catkins before they are open and store them in water in the greenhouse to enhance seed development.

Some viable seeds were collected on the surrounding Navajo Reservation in May 2003 and seedlings were produced at the Navajo Forestry Nursery. These seedlings will be transplanted into 1-gal (4-l) containers and kept in the nursery until their sex can be determined. Hopefully, we will eventually be able to cross-pollinate the Navajo aspen with plants from the Hopi Reservation.

Summary

The goal for restoring riparian sites on the Hopi Reservation is ultimately to create a sustainable plant community. By providing seedlings to these areas, and thereby increasing the genetic diversity, we hope to create a willow and cottonwood ecosystem that will survive and reproduce. The success of this goal is hinged upon planting materials that are suited to riparian conditions, and using locally adapted plant species for the production of future seed sources. With the cooperation of the USDA Natural Resources Conservation Service, the USDA Forest Service, the Navajo Department of Forestry, and the Hopi Tribe, the first steps will be taken to restore genetically diverse communities to critical riparian sites.

Acknowledgments

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Status of Pesticide Registrations for Forestry

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Abstract: The status and number of pesticides registered and available for forestry uses is changing rapidly, especially for insecticides and fungicides. Several pesticides which were considered critical for some forest pest management programs are no longer available; others are still available but with significantly altered application rates, methods, reentry intervals, and use patterns. Additional registrations are currently under review and their future is difficult to predict. The processes that caused these changes are still in play, resulting in uncertainty regarding the availability of products in the future. There are opportunities for pest managers to play a critical role in maintaining registrations of forestry pesticides.

Keywords: reregistration, FIFRA, FQPA, pesticides

The Federal Insecticide, Fungicide, and Rodenticide Act, and the Food Quality Protection Act

In 1988 the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) was amended in an effort to accelerate the reregistration of pesticides registered prior to 1984. The amendment requires registrants to develop and submit data to support the reregistration of an active ingredient; this review of all data is submitted to the US Environmental Protection Agency (EPA). Reregistration requires a thorough review of the scientific database used to support a pesticide registration. Additional purposes of the review are: 1) to reassess the potential hazards resulting from currently registered uses and application rates; 2) to determine if there is a need for additional data on health and environmental effects; and 3) to determine if the pesticide meets the criteria of causing “no unreasonable adverse effects” required by FIFRA.

The Food Quality Protection Act of 1996 (FQPA) amended FIFRA to require reassessment of all existing tolerances. It is designed to protect women, children, and infants from adverse effects of pesticides and was effective immediately on signing by the President. The act requires that EPA complete, by 2006, the review of all tolerances in effect as of the date FQPA was enacted. The FQPA also required an assessment of cumulative effects of chemicals with a common mechanism of toxicity, and introduced the concept of the reference dose, or “risk cup.”

FQPA Review Process

There are 6 phases in the FQPA review process. The review process for the organophosphate insecticides serves as the model.

Phase 1 (30 days)—Registrant “Error Only” Review

EPA sends human health and ecological risk assessments to the technical registrant(s) of the pesticide for a 30-day error correction review, asking them to identify and correct any computational or other errors. Soon after, EPA sends risk assessments to USDA/other Federal agencies for their review and comment.

Phase 2 (up to 30 days)—EPA Considers Registrants' Comments

EPA considers errors identified by the registrant(s) and corrects the errors as appropriate. EPA considers comments from the USDA and other Federal agencies, and transmits an overview summarizing the risk assessments to the agencies. EPA completes the risk assessments for public release.

Phase 3 (60 to 90 days)—Public Comment on Risk Assessments and Risk Characterization

EPA publishes a Federal Register (FR) notice announcing availability of the risk assessments and related documents from the public docket and EPA Web site, and opens a 60- to 90-day comment period. Federal, state, and tribal agencies engage stakeholders in dialogue on risk assessment/characterization.

Phase 4 (up to 90 days)—EPA Revises Risk Assessments, Develops Risk Reduction Proposals

EPA considers public comments received during Phase 3, revises the risk assessments, and develops risk reduction proposals. EPA briefs other federal agencies, and states and tribes (often through a regulatory partners conference call). EPA also participates in USDA-led stakeholder conference calls. EPA and USDA may host a technical briefing and/or stakeholder meetings to discuss the revised risk assessments and risk reduction proposals. The Federal agencies may begin a dialogue with stakeholders on benefits and transition.

Phase 5 (60 days)—Public Comment on Risk Reduction

EPA publishes an FR notice announcing availability of the revised risk assessments and response to comments. EPA also releases and invites public comment during the next 60 days on risk reduction options, a qualitative use impact discussion (when EPA has identified risks of concern), and a discussion of potential transition issues. The public is encouraged to suggest risk management proposals. Federal agencies begin a dialogue with stakeholders on risk reduction and risk management.

Phase 6 (up to 60 days)—EPA Develops Final Risk Management

EPA considers comments and risk management ideas submitted during Phase 5. With input from other agencies, EPA develops a risk management decision. EPA releases the decision, including benefits discussions/assessments as needed. USDA may issue a transition strategy.

One of the major concerns voiced by growers of minor use crops is that registrants will bargain away registrations for these crops in order to ensure inclusion of major uses into the risk cup, since all nonoccupational sources of pesticide exposure must be evaluated under FQPA.

Pesticide Reregistration Terms

Several terms are important to understand if we are to fully appreciate the reregistration process. The Reregistration Eligibility Decision (RED) summarizes EPA's risk assessment conclusions and outlines any risk reduction measures necessary for the pesticide to continue to be registered in the US. The Interim Reregistration Eligibility Decision (IRED) is issued for a pesticide undergoing reregistration that requires a RED and needs a cumulative risk assessment. The IRED may include taking risk reduction measures, such as reducing risks to workers, and removing uses the registrant no longer supports in order to gain benefit of the changes before the final RED can be issued. A Tolerance Reregistration Decision (TRED) reports on tolerance reassessment progress and interim risk management decisions. It is issued for pesticides that require tolerance reassessment decisions, but which are not subject to reregistration for one of several reasons.

Reregistration reviews can result in one or more of several possible situations: there may be no changes in the registration or label; some uses may be deleted; and/or application rates, timing, method of application, and annual application rates may be changed. In addition, some reregistration reviews have resulted in significant changes in the type and amount of personal protective equipment (PPE) required, as well as changes in the reentry interval (REI). In extreme situations, registrants have requested cancellation of registrations rather than accept changes required by the RED.

Many pesticides of interest to forestry have undergone reregistration review or will undergo review in the future. The EPA Web site (http://www.epa.gov/pesticides/reregistration/candidates.htm) lists the agency's planned actions for FY 2003 to 2004. There are 20 candidates for REDs in FY 2003, and 23 in FY 2004. There are 6 candidates for IREDS in FY 2003, and 4 in FY 2004.

Helpful Hints

There are some "notes to the wise" that may be helpful. EPA and the registrants have begun contacting growers individually regarding worker exposure issues for some products, and can be expected to continue this effort. Be absolutely certain to mix and apply all pesticides exactly in accordance with label instructions. Use the EPA Web site (http://www.epa.gov/pesticides), reviewing it regularly for issues that may affect your interests. Carefully review labels of the products you use and be sure they reflect what you actually do, not what you could do. Look especially at rates, timing, frequency, method(s) of application, and role in relation to IPM-based pest management programs. Identify alternative pesticides; develop market analyses and benefit statements. Communicate your needs to the registrant and be prepared to help defend the uses you are interested in. Be proactive rather than reactive.

The reregistration of pesticides is a complex and long term process. Minor uses, such as forestry and nurseries, are especially vulnerable to loss unless the importance of their use is made clear to registrants and the EPA. Pest managers can play a critical role in ensuring that important pesticide registrations are not lost.

Potential Use of Containerised Willow Transplants in the Falkland Islands

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Abstract: In November 2002, 5 *Salix* spp. clones were brought from the UK to the Falkland Islands. The objectives were: 1) to determine if transfer from the Northern to the Southern Hemisphere would be successful; 2) to produce containerised willow with strong root systems and top growth that would establish and provide shelter more rapidly; and 3) investigate whether cuttings would grow better if grown in containers rather than outplanted directly into the soil as nonrooted cuttings.

Preliminary results (3-month growth) appear to indicate that the containerisation of willows significantly improves shoot and root growth. Of the 5 species evaluated, *Salix viminalis* and *Salix* x *dasyclados* have produced willow plants with superior quality and vigour compared with the rest of the varieties. These varieties have also shown continued accelerated growth (length and number of primary shoots) between January and March 2003 in a controlled environment.

In early September 2003, the willows will be outplanted out on a commercial farm on cultivated land to test the impact of plant quality on subsequent field performance—survival, growth, disease status, and stability. This will provide information on species selection, potential use, and economic viability of willows in the Falklands.

Keywords: willow, clones, containerisation, Falkland Islands, *Salix*, utilisation

Introduction

The Falkland Islands are an archipelago in the South Atlantic Ocean (latitudes 51° 00' and 52° 30' south; longitude 57° 40' and 61° 30' west) approximately 450 km (280 mi) northeast of Tierra del Fuego. There are approximately 2,500 residents, 10% of whom live in rural areas. Topography is mainly rolling hills and plains, and the islands are naturally treeless.

Most of the 90 farms are family units of approximately 13,500 ha (33,360 ac). Nowadays the economy is based mainly on fishery licensing management and sheep farming for wool, the main economic base of the islands for the past 160 years. At its peak in 1900, there were approximately 800,000 sheep (Kerr 2002).

The climate is maritime, cool and windy. There is a narrow temperature range and the windiest months are October and November, when gusts of over 120 km/hr (75mi/hr) have been recorded. The total annual precipitation level does not exceed

620 mm (24.5 in) and is evenly distributed throughout the year, with ranges between 350 mm (14 in) on west Falkland to 620 mm on east Falkland. Mean sunshine hours are relatively low due to the high frequency of cloud cover.

Since the islands were colonised in 1764, attempts have been made to grow trees mainly for amenity and shelter purposes. These attempts have had varying degrees of success. Some species, such as Monterey cypress and lodgepole pine (*Cupressus macrocarpa* and *Pinus contorta*), have proved to be successful. However, there is still a need for quick growing shelter and to diversify the range of tree species planted on the Falkland Islands (Low 1999; Palmer 2001; Olave 2003).

Willow is one of the fastest and easiest plants to propagate. When willow is inserted into the ground, cuttings root and grow. However, in the Falkland Islands environment, with soil and climatic limitations, this type of establishment has been difficult.

Interest in growing willows for different uses on the Falkland Islands began in 1990. During this period, a number of nonrooted willow cuttings (some from the Northern Hemisphere) were outplanted into a damp sheltered site using species occasionally grown locally for hedging to assess their suitability (McAdam and others 1990). A second attempt with nonrooted cuttings was carried out in 1999, where a wide range of species/varieties of willow from the Northern Hemisphere were tested and outplanted directly into the soil at 4 different sites (Dawson 1999; Olave and others 2002).

Unfortunately, both attempts failed due to poor establishment. Probably the main reasons were prolonged dry weather after outplanting, asynchronous seasonality of the cuttings brought from Northern to Southern Hemisphere, competition mainly from weed and grass vegetation, and inadequate ground preparation (Olave and others 2002).

The overall objectives of this new study are: 1) to investigate whether willow cuttings of 5 different clones would grow better if initially grown in containers rather than outplanted directly into the soil as nonrooted cuttings; and 2) to test whether the seasonality of the growth cycle from Northern to Southern Hemisphere can be broken. Subsequently, the feasibility of outplanting and the economic and biological tradeoffs in terms of root development and establishment in the Falkland Islands will be determined.

This paper reports followup work on the attempt to introduce willows through the container production of 5 willow clones grown under controlled condition for 3 months. Information on further assessments of their potential under field conditions in the Falkland Islands is also presented.

Material and Methods

Plant Material and Growth Conditions

Healthy cuttings of 25 cm (10 in) in length with a minimum diameter of 8 mm (0.3 in) were collected from woody willow material. Material from 5 different clones (Table 1) was obtained from 1-year-old dormant stems grown outdoors in 2002 at Northern Ireland Horticulture and Plant Breeding Station, Loughgall, Co Armagh, and transported to the Falkland Islands in November 2002. The selection of the 5 clones was based on the following factors: 1) ability to be used as shelterbelt, energy, or bioremediation; 2) suitability for browsing and amenity purposes; and 3) tolerance to acid peat soils with low nutritional status, wind resistance, and dry climate.

Cuttings were stored at –2 °C (28.5 °F) until early January when half of them were containerised and grown in a greenhouse. Sixty cuttings per clone were planted in 21 (0.5 gal) pots and filled with a commercial medium (Sinclair, SHL Peat-Bark) and sand. Controlled release fertiliser (Scotts, 14N:9P_2O_5:14K_2O, 8 month longevity) was incorporated at 300 g/m^3 (0.3 oz/ft^3) and irrigated as needed. The experiment was a randomised block design with 5 treatments. Each treatment consisted of 3 replications of 20 cuttings per replication. Day and night temperatures were kept at 15 °C and 9 °C (59 °F and 48 °F), respectively, for 16 weeks.

This experiment will be continued in September 2003, when rooted and nonrooted cuttings will be outplanted on commercial farmland that is already prepared.

Table 1—Willow clones used in the study.

Species	Characteristics
Salix x *calodendron*	Hybrid between *Salix caprea*, *S. cinerea,* and *S. viminalis*. It has proved to be a very robust variety in trials across the UK, dealing particularly well with poor exposed sites. Not the highest yielding variety, but consistent.
Salix eriocephala x *S. exigua* 611	Hybrid of Canadian origin that has given good yield in Northern Ireland. More importantly, it has shown no susceptibility to the European strains of rust.
Salix viminalis 78183	Swedish clone and the most widely planted in their biomass programme. The yield is moderate, but the clone has shown consistent results over a wide range of sites.
Salix x *hirtei* 'Reifenweide'	Hybrid with *Salix cinerea* x *S. viminalis* x *S. aurita*. A very robust clone, dealing successfully with poor sites and exposed conditions. The hybrids with *S. cinerea* do not tend to suffer to the same extent with the rust species *Melampsora epitea*, but are susceptible to the less problematic *M. caprearum*.
Salix x *dasyclados*	Hybrid with the same parentage as *Salix* x *calodendron*. It was planted with some success in the Falkland Islands some years ago. Like *Salix* x *calodendron,* it is a robust clone. Unlike *S.* x *calodendron*, it has a rather spreading, untidy growth habit.

Data and Analysis

During the first week of April 2003, willow plants were taken out of the greenhouse to let them harden off before winter. Length and number of shoots were recorded and 3 samples of each variety from each replicate were destructively harvested for the determination of root and shoot fresh and dry weights. Leaf samples were taken at the same stage and analysed for nitrogen (N), phosphorus (P), and potassium (K) content.

Conventional analysis of variance was used to analyze root and shoot weights, root-to-shoot ratio, and number and length of primary willow shoots.

Soil samples were taken in January 2003 in order to determine the fertility of the substrate where the rooted and nonrooted willow cuttings will be outplanted. The samples were combined to give bulked samples for chemical analysis and pH.

Results and Discussion

In this first stage of the study, 5 clones of willow cuttings were containerised, grown in a greenhouse for 3 months, and measured at the end of that period. *Salix viminalis* and *Salix* x *dasyclados* emerged as the overall leaders in terms of primary shoot production, length of shoot, and morphological attributes (Tables 2 and 3). However, these preliminary results do not provide information on their field performance. Future elements of the programme will involve assessment of parameters related to outplanting, management, and usage.

Table 2—Average length and number of primary shoots of willows after 3 months growing in the greenhouse in the Falkland Islands.

Willow clones	Shoots	Primary shoot
	number	*cm*
Salix x *calodendron*	4.0 a	41 a
Salix eriocephala x *S. exigua* 611	4.0 a	54 b
Salix viminalis	6.0 b	41 a
Salix x *hirtei* 'Reifenweide'	4.5 a	45 a
Salix x *dasyclados*	5.0 a	56 b

Values in one column followed by the same letter are not significantly different at $P > 0.05$.

Number and length of willow primary shoots are important components of growth form and affect their potential use (Table 2). *Salix viminalis* and *Salix* x *dasyclados* show a slight tendency to produce greater numbers and length of shoots, respectively, than the other cultivars. These measurements, plus the field response, will help to evaluate which clones will be more suitable on the Falkland Islands environment if characteristics such as density or height are seen as desirable.

Measurements of root and shoot dry mass of the plants after 3 months growing in the greenhouse (to be linked with survival potential and plant growth following outplanting) are shown in Table 3. Analysis of variance of the 5 clones showed dry and fresh weight of roots and shoots of *Salix viminalis* were significantly greater than other cultivars. These parameters in *Salix* x *dasyclados* were not significantly different, but the clones did grow slightly better than other cultivars. Root and shoot ratios are higher for *Salix viminalis* (Table 3) than other clones, and this may confer an advantage following outplanting. Surviving plants will be evaluated and compared with the performance of nonrooted cuttings.

The leaf N, P, and K content varied from 1.12 to 1.92%, 1.04 to 1.84%, and 0.19 to 0.31%, respectively (Table 4). These levels of N, P, and K in the leaves are not likely to be reducing growth rate (Parfitt and Stott 1987; Vihera and Saarsalmi 1994). Furthermore these nutrient levels reflected that the amount of controlled release fertiliser applied has been adequate. The reason for differences in nutrient content of clones was not clear, but it may reflect better growth. This could impact shoot and growth potential in the field soils where nutrient levels are generally low.

Salix hirtei 'Reifenweide' (Table 4) stores more N, P, and K in the leaves than other cultivars, which could indicate better leaf development and shoot growth. Such differences will be evaluated in the field where nutrient levels will be linked to outplanting success and growth rate. To achieve greater predictability in how willow will perform after outplanting, foliar nutrient levels will be an important measure of site suitability.

Field Outplanting

The site selected for willow outplanting is a relatively shallow uniform layer of dry peat, and has already been cultivated. However, the nutrient levels and pH of the soil

Table 3—Average dry and fresh weight of shoot and root of 5 willow clones after 3 months growing in a greenhouse in the Falkland Islands.

Willow clones	Root fresh weight	Root dry weight	Shoot fresh weight	Shoot dry weight	Root-to-shoot ratio
	- - - - - - -	- - - - - - -	*g*	- - - - - - -	
Salix x *calodendron*	19 a	3 a	37 a	12 a	0.27 a
Salix eriocephala x *S. exigua* 611	18 a	3 a	44 a	15 a	.22 a
Salix viminalis	28 b	7 b	46 b	17 b	.40 b
Salix x *hirtei* 'Reifenweide'	19 a	4 a	39 a	14 a	.30 a
Salix x *dasyclados*	23 a	4 a	42 a	14 a	.28 a

Values in one column followed by the same letter are not significantly different at $P > 0.05$.

Table 4—The amount of nitrogen, phosphorus, and potassium in the leaves after 3 months growing in the greenhouse in the Falkland Islands.

Willow clones	N	K	P
	- - - - - - - - -	*percent*	- - - - - - - -
Salix x *calodendron*	1.25	1.47	0.29
Salix eriocephala x *S. exigua* 611	1.37	1.81	.19
Salix viminalis	1.12	1.04	.21
Salix x *hirtei* 'Reifenweide'	1.92	1.84	.31
Salix x *dasyclados*	1.30	1.56	.21

were considered unsatisfactory for cultivation. Natural shelter was planted on the windward side of the site.

The soil is acid and infertile (Table 5), and could result in poor survival, low growth rate, and difficult establishment of either rooted or nonrooted willow cuttings. The successful establishment of willow for potential different uses will require knowledge of any imbalance and nutritional deficiencies in either plants or soils (Parfitt and Stott 1987), as fast growing willow species have a high nutrient requirement (Vihera and Saarsalmi 1994). Site factors, such as nutrient content, moisture, and pH of the soil, will have a strong influence on the growth and productivity of willows.

On willow sites in the British Isles, the addition of fertiliser in the planting year is not considered necessary. However, considering that rooted and nonrooted willow may not have an adequate reserve to support the first growing season on the Falkland Islands, it is necessary to apply phosphorus fertiliser before and after outplanting (Low and McAdam 1999) and raise the pH towards neutral. Subsequent applications will depend on growth and foliar analysis.

Potential Use for Willows

Since the 1960s, many researchers have become interested in growing varieties of *Salix* spp., as they exhibit a wide range of uses and tolerance of extreme ecological ranges. Willows are utilised in many ways, for example pulp production and woodchips for fuel. These woodchips provide a source of renewable energy that is widely used in Sweden and the UK to reduce air pollution from fossil fuels (Tabbush and Parfitt 1999). In places like the Falkland Islands with environmental limitations, use in shelterbelts would play an important role due to the need to protect livestock and agricultural crops from the strong winds.

The majority of willows provide excellent shelter material, either as quick growing windbreaks behind which other more permanent species could establish, or windbreak species themselves. Other uses, such as energy (heat production), bioremediation (biofiltration for treating a wide range of waste), browse (fodder), and amenity (gardening) may be included into a practical application programme.

Table 5—Soil analysis of the outplanting site on Fitzroy Farm, East Falklands.

Soil analysis	Level
pH	4.11
Nitrogen (mg/L)	0.5
Potassium (mg/L)	405
Phosphorous (mg/L)	18

Energy

In the Falkland Islands, willow could be grown to provide a quick shelterbelt around small paddocks. After several harvests, enough material could be accumulated to provide heating using small scale heating systems. It might also be a valuable component of a sustainable organic farming system. It may help in replacing both oil imports and peat consumption from natural reserves. Based on information on farm and housing size and growing conditions from the UK, it is suggested that, to cover individual heating requirements or crop protection in the Falkland Islands, it would be necessary to manage at least 2 ha (5 ac) of willows per house farm.

Bioremediation

The potential use of bioremediation would help the islands to achieve a sustainable economic growth, within the concept of organic status, due to the maintenance of a clean environment. This would improve the fragile rural economic infrastructure of the islands and increase the opportunities for diversification. There are a number of species of willow that produce extensive shallow root systems, providing excellent active phytoremediation systems, removing nutrient elements from wastes. Dawson (1999) suggested 2 major implications for such a system: 1) Animal manure can provide nutrition for the willow crops, while the willow can actively detoxify the waste, removing sensitive elements such as phosphates, nitrates, and some heavy metals. This is particularly relevant on the islands where soils are nutritionally poor. 2) In a climate where rainfall is low, the added water in the waste could prove as valuable as the nutrients in promoting growth of the willow.

Amenity Plantings

Willows are well adapted to human-modified habitats and have been an important part of the human landscape in a wide range of locations. They are commonly included in amenity planting programmes for their attractive foliage, bark, stems, and catkins. It would help to improve Falkland Islands farm settlements where there are no trees and shrubs around houses and gardens. Finally, it is important to mention that there are already willows growing locally that were introduced for shelter and browsing. Willow foliage has been proven elsewhere to be good fodder for sheep, cattle, and horses, as well as for wildlife.

Conclusions

Although the main objective is to introduce willows into the Falkland Islands as a windbreak, it is believed that other uses, such as energy and bioremediation, could be a real alternative, as agriculture has been forced to diversify towards sustainable economic and organic status. Willow already grows widely in a range of situations on the Falkland Islands, clearly demonstrating some evidence for their potential use. Basic production work on willow has been accomplished. However, further information is required on land suitability, performance of other varieties, and nutritional aspects. The containerisation of willow cuttings with better root systems and top growth could considerably help in establishment and quick growth.

In the early stages of this work, where willow was grown under controlled conditions, *Salix viminalis* and *Salix* x *dasyclados* have performed best. Subsequently, rooted and fully dormant nonrooted willow clones will be outplanted out on a cultivated site at Fitzroy Farm in September 2003 where they could provide an effective shelterbelt and contribute to improving agriculture in a sustainable fashion.

Experience in the UK in development and demonstration of small scale gasification technology to convert wood chips to electricity and heat has shown that, on a reasonable scale, willows could offer the opportunity for use as biomass for energy, bioremediation, and amenity purposes while being used as a shelterbelt.

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Illinois Conservation Reserve Enhancement Program (CREP): A Model for Watershed Restoration

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Keywords: wetland restoration, tree planting, native grasses, incentives

CREP Overview

The Conservation Reserve Enhancement Program (CREP) is an offspring of the Federal Conservation Reserve Program (CRP). CREP combines the CRP with state programs to meet specific state and national environmental objectives. It also provides for voluntary agreements with farmers to convert cropland to native vegetation.

Several differences exist between CREP and the original CRP. CREP is targeted to specific geographic areas. The program is a partnership between the Federal government and the states and other stakeholders; it is "results oriented" and requires annual monitoring. The main difference is that CREP is flexible enough to meet local conditions on the ground.

CREP National Summary

To date, there are 24 states with approved CREP agreements, and 2 states (Indiana and New Jersey) with proposed agreements (Figure 1). These agreements include 30,422 contracts. A total of 489,248 ac (197,992 ha) have been enrolled; 115,901 ac (46,904 ha) have been planted to trees; another 121,500 ac (49,170 ha) have been restored to wetlands and declining habitats.

Illinois Conservation Reserve Enhancement Program

The Illinois CREP is the most successful federal/state/local partnership to ever implement a voluntary, incentive-based conservation program. This program was the model for the Illinois Rivers 2020 program. There are currently 110,000 ac (44,515 ha) enrolled into 15-year CRP contracts on the federal side of the program. The state side of the program has enrolled 67,044 ac (27,132 ha) into conservation easements; the average size of tracts for state enrollment is 66 ac (27 ha). Approximately 90%, or 62,032 ac (25,104 ha), are in perpetual easements, with many of these easements in large, contiguous tracts (Figure 2). The Illinois CREP has the ability to target areas around critical habitats, state and federal areas, and many other sites.

Goals

The goals of the Illinois CREP include: 1) reduce sedimentation in the Illinois River by 20% (Figures 3 and 4); 2) reduce nutrients in the river by 10%; 3) increase populations of waterfowl, shorebirds, and nongame grassland birds by 15%; and 4) increase native fish and mussel stocks in the Lower Reaches by 10%.

Components

The Illinois CREP targets riparian areas defined in the 100-year floodplain (Figure 5). The program also targets highly erodible land (HEL = 12), which is adjacent to the floodplain. It targets wetland restorations throughout the eligible area, and focuses on native vegetation.

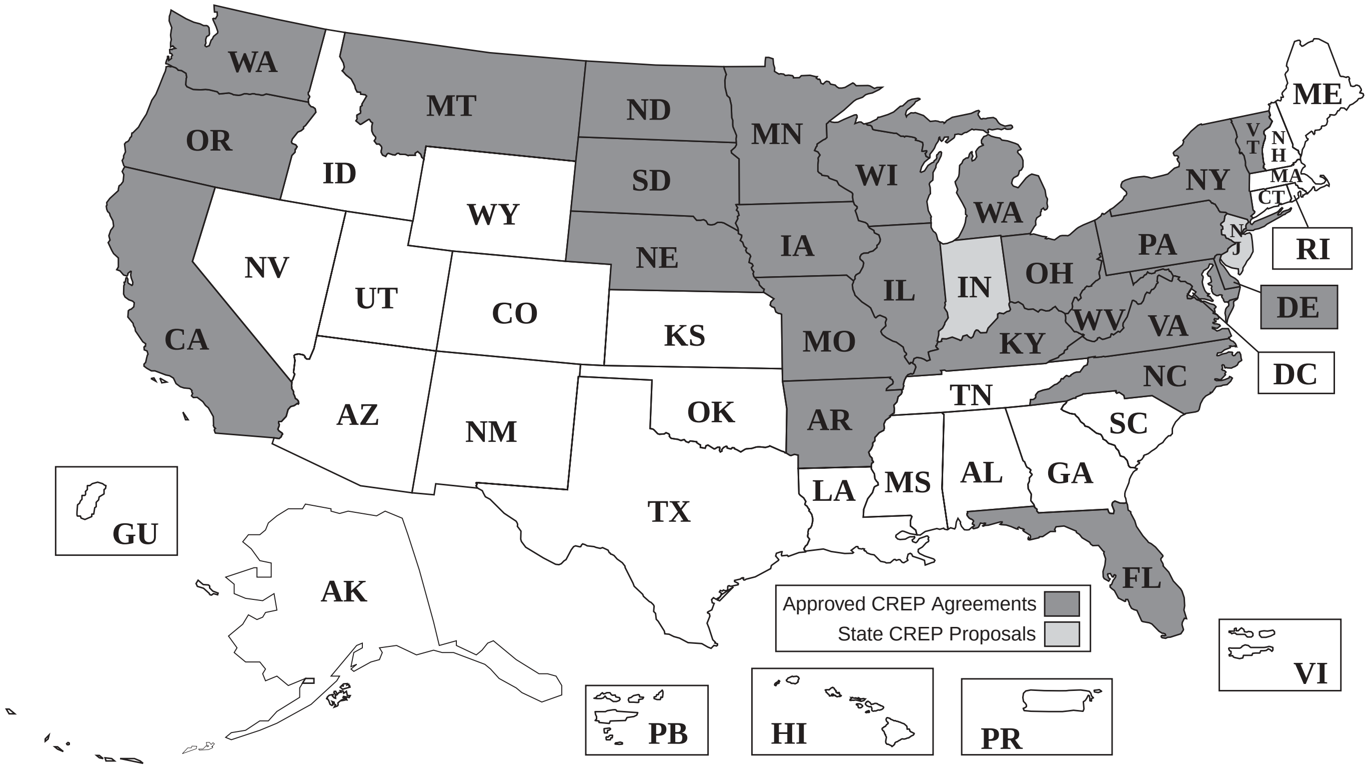

Figure 1—Approved and proposed CREP states. No agreements are pending for states shown in white.

Eligible Land

CREP eligible lands must be located in the floodplain of the Illinois River Watershed or the land must be predominately wetland soils. Eligible land does not need to be owned or operated by the applicant for the previous 12 months for riparian buffers and filters strips; this is necessary, however, for all other practices. Land must have been planted in commodity crops for 2 of the last 5 years.

Noncropped acreage or acreage in another CRP signup can be offered at the same time as cropped ground in the federal side of CREP for a permanent easement. This acreage must meet the 20-ac (8-ha) minimum required for permanent easements, and a field review may be required to determine eligibility.

Permanent easements allow the landowner to maintain recreation rights. In addition, the landowner can harvest trees and can use grazing to maintain native grasses after the CRP contact expires. However, the land cannot be put into agricultural use or be developed.

Enrollment Options

Enrollment in the federal program requires a 15-year CRP contract. The state offers 3 options: 1) a 15-year extension; 2) a 35-year extension; or 3) a permanent easement. The landowner is not required to enroll in a state option.

Incentives

Federal—CRP annual payments, made over the full 15 years of the contract, average US $164/ac (US $405/ha). There is a 30% bonus for riparian land and wetland enrollments, and a 20% bonus for erodible land (HEL = 12). USDA also provides a 50% cost-share in the program. Signup incentive payments are available for riparian buffers (CP22) and filter strips (CP21); practice incentive payments are available for riparian buffers, filter strips, and shallow water areas for wildlife (CP9). In addition, there is an annual maintenance rate.

State—Lump sum payments are made after permanent easements or contract extensions are recorded against deeds, averaging US $515/ac (US $1,271/ha). There is a remaining cost share for installation of approved practices, as well as assistance for improvements to non-cropland enrolled in permanent easements.

Eligible Practices for Erodible Land

Eligible practices for erodible land fall into 6 categories under CREP: 1) CP2 for permanent native grasses; 2) CP3 for tree planting; 3) CP3A for hardwood tree planting; 4) CP4D for permanent wildlife habitats; 5) CP12 for wildlife food plots; and 6) CP25 for rare and declining habitats.

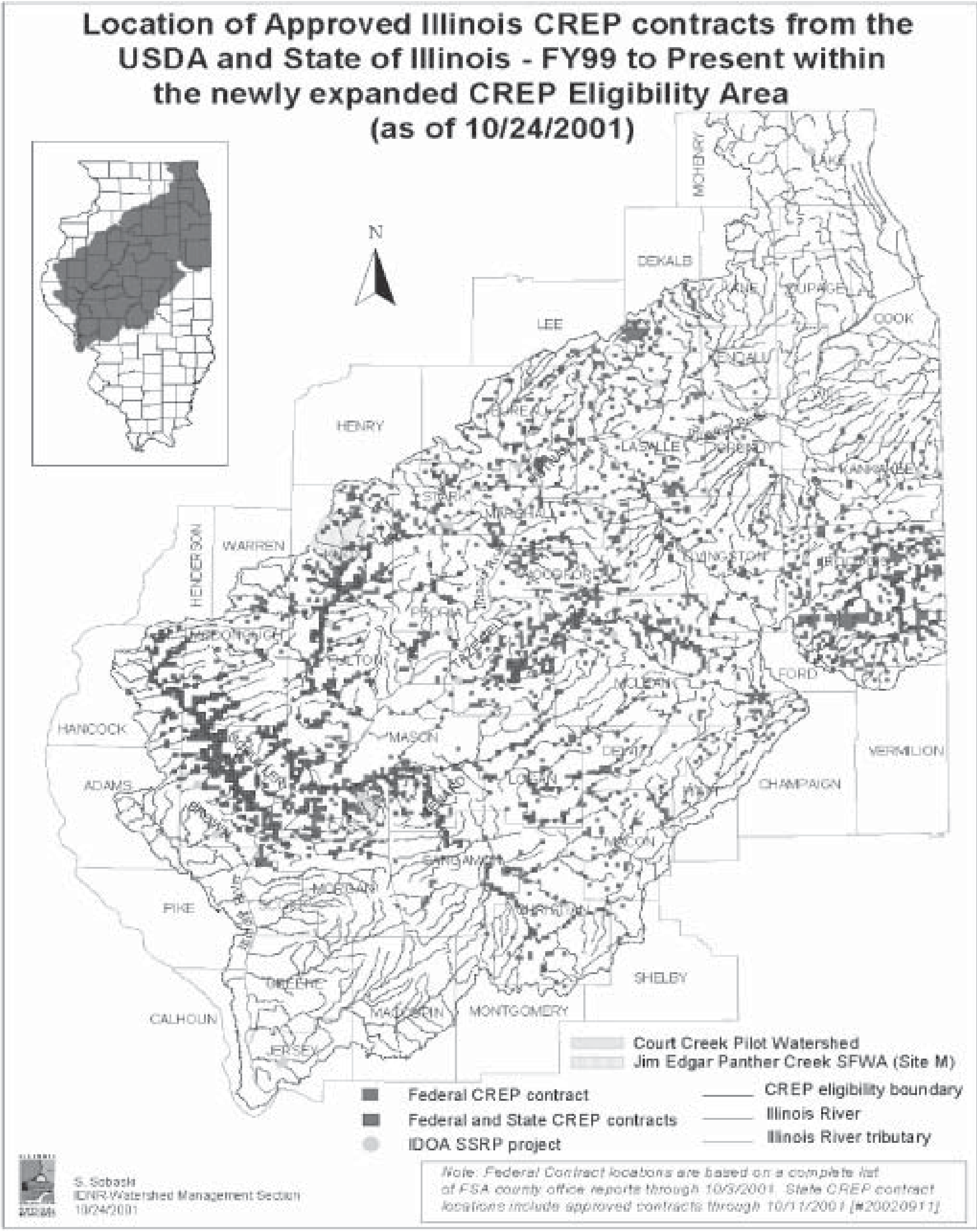

Figure 2—State and federal CREP contracts in Illinois.

Figure 3—Sedimentation impacts can be easily seen, but some impacts are below the surface of the water in critical habitat.

Figure 4—Approximately 90% of the volume in the 54 backwater lakes along the Illinois River has been lost to sedimentation.

Figure 5—Illinois River floodplain.

Contracts under the federal CRP program include 46% in native grasses, 32% in wetlands, and 22% in tree planting. Enrollments in the state program include 64% in wetlands, 26% in tree planting, and 10% in native grasses.

Eligible Practices for Riparian Areas

Eligible practices for riparian areas (100-year floodplain) fall into 8 categories under CREP: 1) CP3A for hardwood tree planting; 2) CP4D for permanent wildlife habitats; 3) CP9 for shallow water areas for wildlife; 4) CP12 for wildlife food plots; 5) CP21 for filter strips; 6) CP22 for riparian buffers; 7) CP23 for wetland restoration; and 8) CP25 for rare and declining habitats.

Administration of CREP

A number of agencies are involved in the implementation of CREP. The USDA Farm Service Agency (FSA) administers all CRP contracts. The Natural Resources Conservation Service (NRCS) determines landowner eligibility and provides technical assistance for Conservation Police Officers (CPO) and the implementation of practices. The Department of Natural Resources (DNR) provides technical assistance for CPO and the implementation of practices, determines eligibility for additional acres, and administers state funding. The Soil and Water Conservation Districts (SWCD) hold easements, market the program for state options, and administer enrollments and permanent easement execution. The Illinois Department of Agriculture (IDOA) monitors assistance, provides assistance to SWCD, and assists with program policy. The Illinois Environmental Protection Agency (IEPA) also monitors assistance, provides marketing assistance, works with 319 grants, and assists with program policy.

CREP Advisory Committee

The CREP Advisory Committee is a subcommittee of the State Technical Committee. The Advisory Committee provides guidance to the implementing agencies. In addition, it aids in the review and development of procedures, develops program outreach and marketing, reviews monitoring results, and reviews the annual report.

The Advisory Committee members include the implementing agencies, US Fish and Wildlife Service, Illinois Farm Bureau, Illinois Cooperative Extension Service, The Nature Conservancy, and Pheasants Forever.

Importance of the Illinois CREP

The Illinois CREP is an extremely successful program. It leads all CREP programs in the nation with the greatest number of total acres enrolled, the greatest number of permanent easements, the greatest number of wetland restorations, and tremendous local support. It is important for both economic and environmental reasons. The Illinois River Basin contains such critical resources as 10 million ac (4,047,000 ha) of prime farmland, a vital transportation system, drinking water for a million people, a variety of industries, and habitat for fish and wildlife.

Illinois has appropriated US $46.7 million to date for 132,000 ac (53,400 ha). The USDA has committed US $262 million to the program. The next 100,000 ac (40,500 ha) will cost an estimated US $250 million, with every state dollar leveraged by approximately 4 federal dollars.

Illinois CREP has been successful for a number of reasons. Easements are held at the local level by SWCD. There are a number of options available to the landowner, and there is tremendous local support because money flows to the local level for implementation. A large number of older producers are enrolled in the program. And finally, the program provides for high soil rental rates with relatively low land prices.

Current Status of Illinois CREP

The last open enrollment for CREP ended in November 2001 when the federal acreage cap was reached and state dollars were expended. In December 2002, a new memorandum of agreement (MOA) provided for 100,000 additional acres through December 31, 2007. Based on this MOA, a reopening of enrollment is anticipated in February or March 2004.

Illinois Forestry Development Act of 1983 and the IDNR Free Seedling Program

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Abstract: Information on one of the most important acts affecting forestry in Illinois in recent years, the Illinois Forestry Development Act of 1983 (FDA) is presented. How this act relates to and affects the state seedling program and the events that make the program what it is today are also discussed.

Keywords: tax incentives, forest management plans, cost sharing

Introduction

In the early 1980s, sectors of the Illinois forest community were concerned about the direction of federal forestry programs, such as the Agricultural Conservation Program (ACP) and Forestry Incentives Program (FIP). As a result, the IDO Division of Forestry, University of Illinois, and Southern Illinois University hosted the first and only Forestry Summit in Springfield in 1982. As a result of that meeting, 2 important events occurred:

1. The chairmen of the 2 Illinois forestry schools, along with a state senator and a state representative, drafted the Illinois Forestry Development Act (FDA). It was passed into law in September 1983.
2. An 11-agency forestry agreement was signed to promote and implement conservation and forestry related resources in a more unified approach. This action formalized the intent of the Illinois Forestry Development Act.

Now a few facts about the Illinois Forestry Development Act.

Illinois Forestry Council

Due to the success of the forestry conference and the movement for an 11-agency forestry agreement, the act created a legislatively mandated council. The Council currently consists of 24 members: 4 members of the general assembly; the directors of the Department of Natural Resources (DNR), the Department of Agriculture (DOA), and the Department of Commerce and Community Affairs (DCCA); the Illinois Farm Development Authority; the Lieutenant Governor of the Rural Affairs Council; the Illinois Governor's Office; Illinois Association of Soil and Water Conservation District; 2 private landowners; 2 industrial forest landowners; an urban interest; the Illinois Arborist Association; an environmentalist; 2 members of the wood industry; the forestry departments of both Southern Illinois University and the University of Illinois; USDA Natural Resources Conservation Service; and the Shawnee National Forest. The Council also has 3 standing committees on stewardship and education, urban forestry, and rural development. Additional concerned citizens serve on these committees.

The Council is charged to study and evaluate the forest resources and forest industry in Illinois. It determines the uses, benefits, and services these resources provide, including opportunities relating to forest industry, as well as staff and funding needs for the forestry programs, education programs, soil and water conservation, and wildlife habitat improvements. The Council continues to provide a comprehensive framework to maintain and enhance the forest resources and encourage cooperation among all concerns. The Council also serves as the department's stewardship advisory committee, Forest Legacy subcommittee, Forest Land Enhancement Program Committee, and the Urban Forestry Advisory Committee. In addition, the last 2 Statewide Forest Plans were prepared by the Council.

Forestry Education

The act amended the Illinois Cooperative Extension Act regarding forestry education.

Loans

The act amended the Illinois Farm Development Authority to provide low-cost loans to the forest industry.

Harvest Fees

The act amended the Illinois Timber Buyer Licensing Act to require timber buyers to collect and pay the DNR a 4% harvest fee (some will call it a stump tax) on all timber purchased in Illinois. The 4% harvest fee can be used for 2 purposes: 1) to support the Council activities; and 2) to fund the Illinois Forestry Development Cost Share Program.

Forest Management Plans

The Act requires landowners who would like to participate in the FDA programs to have an approved Forest Management Plan. Participation is voluntary, but must include the growing of timber products as one of the primary management goals.

Tax Incentives

The act amended the Farmland Real Estate Assessment Tax Act. In Illinois, agricultural land is assessed based on soil productivity to produce a crop. Pasture land is assessed at a rate based on one-third of the crop land productivity and other land is assessed at one-sixth of crop land productivity. Forest land usually falls in the "other" category. However, in parts of the state, if ownership includes forest land only, it could be taxed as an estate/residential classification at a much higher rate. In those counties, forest land needed to be a part of a working, crop-producing farm to get a reasonable rate. The Forestry Development Act requires forest land under an approved Forest Management Plan to be guaranteed the one-sixth rule. Today in some counties, you must have a forest management plan on your forest land to be considered for the tax break. This rule can reduce your taxes to approximately US $1.00/ac. The tax assessment is based on the county in which the property is located.

Cost Sharing

The Forestry Development Act created the Forest Development Cost Share Program. To participate in this program, a landowner must have at a minimum of 5 ac of forest land and an approved forest management plan. This program can be used separately or in conjunction with Federal programs. It is a 75% cost share program covering such traditional items as tree planting, purchases of seedlings from a private nursery, site preparation, fencing, forest stand improvement, and so on. This cost sharing program operates very much like the old Stewardship Program, FIP, ACP, or the new Forest Land Enhancement Program (FLEP). If the state FDA Cost Share Program is combined with a federal program, the federal program pays the landowner first and the state pays second. When the Conservation Reserve Program (CRP) started, the federal program paid 50% and the state FDA program paid 50%. The landowner cost was zero. That has changed a bit; the landowner now pays about a quarter of it. This gives the landowners some ownership in the practices on their land.

As a result of the FDA Program, there are currently 7,885 forest management plans that have been approved. These plans guide landowners on program use and care of 384,766 ac (155,710 ha) of forest land. Illinois has provided more than US $11 million in cost sharing in the last 19 years.

Illinois Seedling Program

The Illinois DNR operates 2 nurseries for the production of bareroot plant materials for use by Illinois landowners and state agencies. These plant materials are to be used only for conservation purposes to meet conservation objectives such as reforestation, soil and wind erosion control, wildlife habitat improvement, natural community restoration (that is, prairie restoration), energy conservation, research, and education programs such as Arbor Day. These purposes are probably much like those of most state nurseries.

In the past, the Division of Wildlife and the Natural Heritage Program would give seedlings to landowners for wildlife habitats. At that time, the Forestry Division received a few US Fish and Wildlife funds for operations. Under that program, 2 problems were created: 1) both the Departments of Wildlife and Forestry provided seedlings at or below cost; 2) in most cases, the Department of Wildlife had no plans for the planting of seedlings and did not follow through to ensure proper care and planting. Therefore, a large number of seedlings were never outplanted and had to be destroyed.

With the passage of the FDA programs and the implementation of the Cost Share Program, it did not make a great deal of sense to use state cost share dollars to reimburse the landowners for purchasing state seedlings from the state nurseries. As a result, the no-cost seedling program started. This action enabled the FDA cost share dollars to be extended further and encouraged more landowners to manage their land. Therefore, if the landowner had an approved forest management plan which included cost share for tree planting, the landowner would get free seedlings if available and be reimbursed at 75% of the cost for tree planting up to a maximum per acre.

Conflict Between the State Nursery Program and the Nursery Association

Like most states, there has always been a conflict between the state nursery program and the local nursery association; in our case, that would be the Illinois Nursery Association (INA). The INA, representing about one-fourth of the state's commercial growers (including several out-of-state businesses), contends that a state agency should not be operating a tax-subsidized business in competition with private industry. The INA contends that, in doing so, IDNR is depriving the Illinois nursery industry from entry into the bareroot seedling market. However, commercial nursery production in Illinois is primarily large ball and burlap or containerized stock rather than bareroot seedlings.

There was a demonstrated yearly demand for 500,000 Scotch pine seedlings, as well as another 250,000 seedlings of other conifer species for the Christmas tree market. Because of these concerns about competition, the IDNR stopped producing Scotch pine seedlings in 1981. However, this production was not pursued by the Illinois commercial nurseries. In another case, the DNR refused to bid on the production of plant materials for the Shawnee National Forest, with yearly sales of more than 500,000 seedlings. Again, these contracts were not pursued by any Illinois nurseries. In 1983, to eliminate any possible competition, DNR started growing only native species utilizing Illinois seed sources and many non-native species were discontinued.

Experiences With Private Nursery Contracting

Landowners always have the option of purchasing their own seedlings from any approved source. Further discussion with the INA led to the development of a contract to purchase plant material from private nurseries. INA input had much to do with the contents of the final proposed contract. The Department sought bids for the contract growing of all plant materials in 1988. From a list of 34 prospective vendors, only 6 bids were received. Two out-of-state bids were rejected for failure to comply with state law, and 1 bid was accepted. The accepted bidder later backed out of the contract. Even if the Department could have accepted the remaining bids, only 27.9 % of the 11 million seedlings and plant materials would have been supplied.

In spring 1989, the Department issued another seedling contract to private nurseries. This resulted in 1 successful out-of-state contractor that produced 77,000 gray dogwoods. However, the contractor failed to meet the specifications and packaging requirements of the contract. Eventually, increasing operating costs in the Department and lack of suitable bids resulted in the absorption of the funds for contracting into the Department's operating budget.

New Legislation for Illinois State Nursery

In 1987, legislation amending the state nursery act was passed, which the INA supported, to allow plant materials to be provided at no cost to landowners with an approved management plan. It also required that IDNR must sell the plant material at cost. With the need to have an approved management plan to obtain seedlings, the Department has control over the use of the plant materials and has eliminated the abuse of the system that occurred prior to 1987. Sales are no longer distributed on a first-come, first-served basis. All management plans are approved by a District Forester, Private Land Biologist, or Natural Heritage Biologist. The federal and state cost share programs will reimburse the landowners for part of their cost to purchase seedlings. I believe it works out to be about 93% of the cost if the federal and state cost shares involved reach the "not to exceed" limit.

Summary

When the Conservation Reserve Enhancement Program (CREP) was started, the Department made the commitment that no state nursery stock would be used; all seedlings needed to be purchased from private nurseries. Due to seedling supply problems from the private sector, the IDNR No Cost Seedling Program was initiated. This program is an incentive that gets the Department in the door with the landowner and leads to the implementation of other conservation practices across the landowner's holdings.

Propagation of Giant Cane (*Arundinaria gigantea*) for Riparian Habitat Restoration

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Abstract: The objectives of this research were to identify factors that influence rhizome cutting propagation of giant cane (*Arundinaria gigantea*) and to develop procedures for producing machine-plantable stock for use in canebreak restoration. Phase I of the study investigated factors that influenced culm production from rhizome sections under intermittent mist in the greenhouse. Rhizome sections with at least 10 internodes that were surface planted and exposed to sunlight produced greater numbers of culms compared to those buried and with fewer internodes. Phase II studied the effect of collection date and site (putative genotype) in the production of culms for rhizomes planted in containers under mist in the greenhouse. Culm production varied by date of collection and genotype, with 76% of 435 rhizomes generating at least 1 culm shoot. Results indicate that rhizome cutting propagation may be used to generate machine-plantable stock for giant cane restoration.

Keywords: giant cane, switchcane, *Arundinaria gigantea*, rhizome cuttings, propagation

Introduction

Giant cane or switchcane (*Arundinaria gigantea* (Walter) Muhl.), a native bamboo and member of the Poaceae family, is a component of bottomland and riparian forest ecosystems ranging from southern Maryland west to southern Ohio, Indiana, Illinois, and Missouri, south to central Florida, and west to Texas (Marsh 1977; Simon 1986). Canebreaks, or giant cane-dominated communities, formerly occupied extensive areas in the landscape throughout the region (Smart and others 1960; Platt and Brantley 1993). However, agricultural and urban land conversion, grazing, and fire suppression have greatly reduced canebreak frequency and extent to a limited number of small patches. Canebreaks are now considered to be a critically endangered ecosystem (Platt and Brantley 1997; Bell 2000; Platt and others 2001).

Canebreaks served as habitat for a number of associated wildlife species (Platt and others 2001), including the endangered (or perhaps extinct) Bachman's warbler (*Verivora bachmanii*) and extremely rare Swainson's warbler (*Limnothlypis swainsonii*) (Eddleman and others 1980; Thomas and others 1996; Platt and others 2001). Additionally, giant cane growing in riparian buffers enhances water quality and stabilizes streambanks, reducing nitrates and sediments in ground water and overland flow because of its dense mat of culms and rhizomes (Schoonover 2001; Schoonover and Williard 2003). Consequently, there is considerable interest in canebrake restoration throughout the region. Restoration efforts, however, have been limited by the lack of available planting stock and difficulties propagating the species (Feeback and Luken 1992).

Propagation of giant cane can be carried out either sexually by seeds or asexually through transplanting culms. Seed propagation is problematic because seeds are sporadically produced and are often low in viability (Farrelly 1984; Platt and Brantley 1997). Propagation by digging and transplanting culms and allowing for subsequent spreading of rhizomes is labor intensive, cumbersome, and costly (Platt and Brantley 1993). Using rhizome cuttings to produce planting stock is possible, but little quantitative research has been conducted to determine methods for the successful culm production for the species. The objectives of this research were to identify factors influencing rhizome cutting propagation of giant cane and to develop methods for producing machine-plantable stock for use in canebreak restoration.

Methods

This paper reports on 2 phases of research. In Phase I, the objective was to determine whether culm (shoot) production was affected by the number of internodes within a rhizome section or by exposure to light during propagation. On September 22, 2000, rhizomes and attached culms were hand dug and collected from 4 different sites in Pulaski County, Illinois. Plant material was bulked together, wrapped in polyethylene to avoid desiccation, and transported to the Forest Education and Research Station (ForestERS) greenhouses at Southern Illinois University for processing. Rhizomes were rinsed in water to remove excess residual soil, had any attached culms removed, and were cut into 3 treatments of varying rhizome lengths (2, 4, or 10 and greater (10+) internodes long). Ninety rhizome sections of each treatment length were randomly located in a heated greenhouse on benches covered in perlite medium. Half (45) of the rhizomes of each internode length treatment were placed on the surface of perlite and the other half buried to a depth of 2 cm (0.8 in) to test for treatment differences relative to exposure to light. Rhizomes were misted for 12 seconds every 6 minutes during daylight hours. Data were collected for culms (shoots) greater than 1 cm (0.4 in) long arising from the rhizomes through December 15, 2000. Because of malfunctioning mist and heating systems in the greenhouse, further work with these propagules was discontinued. Comparisons in culm production among rhizomes of varying lengths and planting position were made relative to the number of internodes in each treatment by using chi-square analysis at $\alpha = 0.05$.

Utilizing findings from Phase I, the Phase II study was designed to determine if rhizome sections could be used to generate machine-plantable stock for site restoration. When temperatures were above freezing and the soil was unfrozen, rhizomes were collected by hand-digging from 2 separate cane patches (putative genotypes or clones) at Butter Ridge Road and Hickory Bottoms, in Pulaski County, Illinois, on 2 dates (February 26 and March 23, 2001). Rhizomes were kept moist and cool but not frozen until processing at the ForestERS greenhouse within 2 days after collecting. In all, 139 rhizomes cuttings from collection date 1 and 296 from date 2 were processed. Rhizomes with varying numbers of internodes, but with a mean length of 25.9 cm (10.2 in) (std. error = 0.25 cm [0.10 in]) were planted distal end up slightly off vertical in D40 Deepots (Stuewe and Sons, Inc, Corvallis, OR) having a pot diameter of 6.4 cm by 25.0 cm deep (2.5 by 9.8 in deep) in premoistened peat/composed bark-based medium. At least 3 cm (1.2 in) of each rhizome was left exposed to sunlight and not buried in medium. Pots were placed in a heated greenhouse under a misting regime of 12 seconds every 6 minutes during daylight hours. The number of culms formed that were greater than 1 cm long was noted for each rhizome cutting on April 18, 2001. Rhizomes that formed culms were later transplanted outside to determine future field survival and growth. A chi-square-based test procedure was used to test if the mean percentage of rhizomes that produced at least 1 culm differed by collection date or by collection location (putative genotype) at $\alpha = 0.05$ (Hines and Sauer 1989; Sauer and Williams 1989).

Results

Phase I

Surface-planted rhizomes produced 75 culms compared to the 26 culms produced by buried rhizomes (Table 1). For those rhizomes planted below the medium surface, culm production was independent of the treatment (number of internodes per rhizome section) ($P = 0.200$). When planted on the surface, culm production was dependent on the number of internodes per rhizome ($P \leq 0.001$). Considering the total number of internodes that were in each treatment (2, 4, and 10+), surface-planted rhizomes with 10+ internodes averaged the fewest number of internodes (7.9) needed to produce at least 1 culm. In other words, cutting rhizomes up into sections with fewer internodes (as was the case in the 2 and 4 internode pieces) resulted in fewer culms produced for a given amount of available rhizome tissue. It was observed that when multiple culms formed on a rhizome section, the buds distal to the original culm from which the rhizome was detached tended to sprout first and grow more rapidly, resulting in longer culms than those of more proximal origin.

Phase II

Of the 435 rhizome sections planted in containers, 76% produced at least 1 culm, 28% had produced 2 or more culms, and 9% produced 3 culms. Culm production varied by collection site (putative genotype) and date of collection (Table 2). Rhizomes collected from Hickory Bottoms were more likely to form at least 1 culm than those from Butter Ridge Road for both the first ($P < 0.001$) and second ($P = 0.005$) collection dates. The percentage of culm-producing rhizomes did not differ between dates for collections at Hickory Bottoms ($P = 0.590$); collections from Butter Ridge Road differed among dates ($P < 0.001$). Even though the majority of the rhizome sections were planted below the surface of the medium, 75% of the culms were produced from the portion of rhizome above the surface of the potting medium.

Discussion

Exposure of rhizomes to sunlight during propagation increased the number of culms that were produced, particularly for those that were greater than 10 internodes long. We had noticed that rhizome sections that had previously been uprooted in the field and left exposed to sunlight on the soil surface tended to form culms more often, whereas portion of rhizomes remaining below the surface had fewer culms. Although not specifically referring to the propagation of giant cane, Bell (2000) suggests that other leptomorphic (running) bamboo species can be propagated by rhizome cuttings with no need for light until culms form.

Table 1—The number of giant cane culms generated from buried (2 cm [0.8 in] deep) and surface planted 2, 4, and 10+ internode rhizome sections (n = 45 for each treatment combination) cultured under intermittent mist.

Rhizome placement	Number of internodes per section	Total internodes	Number of culms generated	Mean number of internodes per culm
Buried	2	90	0	—
	4	180	4	45
	10+	575	22	26
Surface	2	90	4	22
	4	180	6	30
	10+	513	65	8

Table 2—Influence of collection date and site (putative genotype) on the production of at least 1 culm from giant cane rhizomes planted in containers.

Date	Collection site	Number of rhizomes	Percentage of rhizomes producing 1 culm or more
February 26, 2001	Butter Ridge Road	76	61
	Hickory Bottoms	63	81
March 23, 2001	Butter Ridge Road	183	77
	Hickory Bottoms	113	82

In our study, we observed light-exposed rhizomes growing on the mist bench surface or those partially unearthed in the field change from their normal tan color to green. This may suggest that the rhizomes become photosynthetic and thus provide energy needed to help stimulate production and the growth of culms. Exposure to light of normally shaded or light-excluded tissues may also stimulate bud break from dormant buds, as is seen in the production of epicormic shoots in trees (Kozlowski and Pallardy 1997). Light stimulation of dormant buds on rhizomes was apparent, as 75% of the culms arose above the potting medium surface even though most of the rhizome was buried.

Simon (1986) and Bell (2000) recommend collecting rhizomes of related cane species for propagation in the late winter and early spring. We found that culm production from rhizome cuttings was greater when collected in early spring compared to those collected in late winter (at least for one putative genotype). However, considerable numbers of culms were also generated from the 10+ internode treatment exposed to light from rhizomes that were collected in the autumn.

It has been recommended that rhizome sections should be 45 to 60 cm (18 to 24 in) long when used for cutting propagation (McClure 1993). In our study, although the rhizomes were about half that size, 76% of them produced culms. Smaller rhizome sections offer the advantage of being able to set out more propagules with the same amount of collected plant material. Additionally, smaller rhizomes are easier to handle for outplanting.

Results demonstrate that giant cane planting stock of a manageable size for machine planting under field conditions can be produced by using rhizome cuttings under intermittent mist. Preliminary outplanting observations indicate that the majority of this planting stock has survived through the first 2 growing seasons and has begun to spread. Containerized giant cane planting stock has great potential to improve the feasibility and success of canebreak restoration efforts.

Acknowledgments

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Success of Hardwood Tree Plantations in Indiana and Implications for Nursery Managers

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Abstract: The purpose of our study was to address the lack of information on the success of hardwood tree plantations established on nonindustrial private forestlands as it relates to the silvicultural practices employed during the first 5 years following planting. Through a telephone survey of afforesting private landowners and a field assessment of their plantations in Indiana, we found that seedling survival was higher on those sites where a mechanical tree planter was used compared to sites where seedlings had been hand planted. Seedling vigor was enhanced through the use of herbicide prior to and subsequent to planting. Nursery managers can help to increase the success of plantation establishment by educating landowners about silvicultural practices and facilitating maintenance of the critical link between nursery production and field establishment.

Keywords: plantation establishment, hardwood seedlings, bareroot, silviculture, site preparation, herbicide application

Introduction

Approximately 5.5 million bareroot seedlings are grown annually in Indiana, with the majority (~85%) of those seedlings produced at the Indiana Department of Natural Resources Division of Forestry nurseries (Jasper-Pulaski and Vallonia). About 100,000 container seedlings per annum, as well as small-scale direct-seeding operations, also provide stock for plantation establishment in Indiana. Plantation establishment success can be loosely defined as the perseverance of seedlings from the establishment phase to canopy closure. Many factors influence the ability of planted seedlings to persevere, including seedling quality (Larson 1977; Farmer 1981; Howell and Harrington 1998), silvicultural practices (Russell and others 1998), and site conditions such as soil quality and animal browse (Graveline and others 1998). Success of plantations established in Indiana is known to be variable, with the main causes of failure attributed to animal browse and competition with undesired vegetation. In the Central Hardwood Forest Region, few studies have quantified nonindustrial private forest land (NIPF) plantation establishment success. The relationship between establishing operational (as opposed to experimental or ornamental) hardwood tree plantations on NIPF and the silvicultural practices employed during the seedling establishment phase is also poorly defined. Most studies that have investigated plantation establishment success have been conducted under controlled experimental conditions, and results and conclusions may not be directly transferable to those established operationally.

Given this situation, identification of those silvicultural practices that lead to successful plantation establishment on an operational scale should both improve future establishment success and provide target areas for cost-share programs. The objectives of this study were to identify silvicultural practices employed during the plantation establishment phase, quantify the survival and vigor of planted seedlings, relate plantation success to the silvicultural practices used, and recognize potential implications for nursery managers when dealing with afforesting or reforesting NIPF owners. This paper summarizes some of the results reported in Jacobs and others (forthcoming).

Methods

All orders placed at the state-operated Jasper-Pulaski and Vallonia nurseries between 1997 and 2001 were obtained. The 3 most abundantly sold hardwood species at these nurseries are black walnut (*Juglans nigra* L.), northern red oak (*Quercus rubra* L.), and yellow poplar (*Liriodendron tulipifera* L.). Those records that contained at least 300 of 1 of the 3 aforementioned species were identified. Of those records, 200 seedling buyers were randomly selected. The 200 seedling buyers were then sent a letter announcing our intentions to contact them by telephone regarding their tree planting. When contacted, we asked afforesting landowners questions pertaining to the type of site preparation techniques used, the experience of the individual(s) who had planted the trees (forester or non-forester), the tools used to conduct the planting (hand or mechanical), and the type(s) of subsequent tending employed. Eighty-seven sites were identified as suitable for sampling.

At each site, we determined the percentage of seedlings surviving and assessed seedling vigor in 3 ways: 1) the number of leaders; 2) whether or not there was evidence of dieback or loss of the terminal leader; and 3) whether or not the seedling was considered to be free-to-grow. A seedling was classified as free- to-grow if it was at least 1.5 m (5 ft) in height and none of the competing vegetation within a 1.5 m radius was greater than two-thirds of the seedling height. The severity of competing vegetation was also assessed in terms of cover and height of grasses, sedges, and rushes, herbaceous vegetation, and naturally regenerating trees, shrubs, and woody vines.

Results and Discussion

Plantation Establishment Success

In each of the 5 years examined, approximately 65% of planted seedlings survived. We found it interesting that there was no additive mortality across the 5 years. There was also little variation in seedling vigor across the 5 years. Dieback or loss of the terminal leader was present on approximately 83% of all seedlings, while about 25% of seedlings had 3 or more leaders. The percentage of seedlings that were free-to-grow ranged from less than 3% in year 1 to almost 50% in year 5. Further examination of the 6 most commonly planted species at year 5 revealed that approximately 80% of black cherry (*Prunus serotina* Ehrh.), 70% of white ash (*Fraxinus americana* L.), 65% of yellow poplar, 50% of white oak (*Quercus alba* L.), 40% of black walnut, and 30% of northern red oak seedlings were free-to-grow. The relatively low percentage of black walnut seedlings that were free-to-grow at year 5 was attributed to a number of apparent species-by-site mismatches. Competing herbaceous cover was lower on sites prepared by a combination of chemical and mechanical practices compared to those sites where either mechanical or no site preparation was employed. Accordingly, Jobidon (1990) found that mechanical site preparation increased the diversity of herbaceous vegetation that recolonized. Height of competing vegetation was also lower on those sites where chemical site preparation was used in conjunction with mechanical site preparation, when compared to the sole use of mechanical site preparation. It is hypothesized that mechanical site preparation allows buried seeds the opportunity to germinate as well as prepares the soil to accept seeds from surrounding sources. Sites that were prepared for planting using either chemical or a combination of chemical and mechanical methods had higher seedling survival than sites where mechanical site preparation was solely used. However, there was no significant difference between site preparation and the absence of site preparation (Figure 1). Site preparation can affect both short- (Lockhart and others 2003) and long-term (McGee 1977) plantation performance and should be implemented appropriately wherever possible.

Similar to the findings of Russell and others (1998), sites that were planted mechanically (Figure 2) had higher survival than those planted by hand. This may be related to seedling roots being too large for the planting hole, which can cause “J-rooting” and may result in poor seedling growth or seedling mortality.

Subsequent herbicide application (Figure 3) plantings established by professional foresters, and those established using mechanical tree planting, resulted in a higher percentage of free-to-grow seedlings. However, those sites that were planted by professional foresters and those that were established with a mechanical planter were also more likely to receive subsequent herbicide applications. Thus, there may be a confounding effect whereby differences associated with planter experience or method of planting are actually related to whether or not herbicide had been applied subsequent to planting rather than the planter’s experience or tool used. Although commonly employed, mowing has not been identified as a substitute for subsequent chemical weed control of hardwood plantations (von Althen 1984).

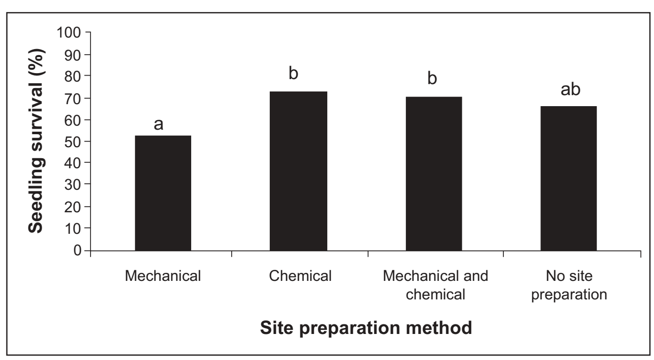

Figure 1—Percentage of seedlings surviving for each site preparation method. Different letters identify significant differences among treatments at $\alpha = 0.10$.

Figure 2—Mechanical planting.

Figure 3—Evidence of subsequent herbicide application in a hardwood plantation established on former pastureland.

Implications for Nursery Managers

Nursery managers have extensive knowledge of the requirements of caring for and growing seedlings and have the unique opportunity to deal with seedling buyers prior to planting. They are also able to direct seedling buyers to extension agents, government personnel, or consulting foresters who understand the diverse objectives of landowners. This dissemination of information is pivotal to ensure the long-term success of the planting. Given that estimates on a national scale indicate that only about 10% of NIPF owners use available technical forest management assistance (Mangold 1994), nursery managers should be prepared to assist seedling buyers. To improve the likelihood of successful establishment, it would be beneficial to remind seedling buyers to match the species they are purchasing to the ecological characteristics of the site they intend to plant. Many nurseries have this information available, and ensuring its availability to seedling buyers should lead to improved seedling survival and vigor. Working with a professional forester to establish the plantation in an appropriate manner (that is, proper site preparation and planting with a mechanical tree planter) should also improve plantation establishment. Nursery managers should maintain an up-to-date list of consulting foresters that may assist in plantation establishment, which could be distributed to seedling buyers. Those who choose not to work with a professional forester could be given extension publications that describe important steps in plantation establishment, such as seedling grading and storage, method of planting, and stand maintenance. The results of this study should also allow nursery managers to reaffirm to afforesting and reforesting landowners that following the recommended stand tending schedule, especially with regard to subsequent herbicide application, will result in development of a stand of trees that becomes free-to-grow at an earlier age.

The target seedling concept states that a quality seedling is one that will thrive upon outplanting (Landis 2003). There is no set standard that can be applied to all species and all sites to ensure success. For a nursery to produce seedlings that will perform as desired upon outplanting, communication between the seedling buyer and the nursery is critical. Identification of what has led to success or failure under specific conditions can help produce better results in the future. Nursery managers can work in conjunction with seedling users to develop standards that generally perform well under a given set of field conditions. Control of nursery cultural practices to meet desired standards of seedling morphological and physiological characteristics can produce a target seedling for a specific tree planting scenario (Rose and others 1990). Ongoing interactions between those who engage in tree planting and nursery managers will hopefully lead to higher outplanting survival. As evidenced by the high mortality rate of seedlings planted on private lands in Indiana, implementation of this practice could lead to a meaningful increase in survival.

Future Directions and Concluding Remarks

Much more information is needed to understand the state of tree planting success on NIPFs. Future research into bottomland plantations, the relationship between seedling establishment and the number and timing of subsequent herbicide applications, and inclusion of stock produced in privately operated nurseries would be beneficial in terms of providing a more complete picture of operational plantation establishment success. Furthermore, our approach should be extrapolated to include plantations established with containerized stock and by direct-seeding. While these methods are currently small in scale compared to plantations established with bareroot seedlings, they may increase in significance in the future. As such, it is important to understand the differences and similarities between these types of stock and their requirements for successful plantation establishment. Increasing the breadth of scope to include seedling handling and storage practices and different tending practices, including fertilization, irrigation, and pruning, will lead to better understanding of how to successfully establish plantations in the Central Hardwood Forest Region.

Several silvicultural practices were found to increase plantation establishment success, presently identified to be around 65%. There was a wide range in survival, from near perfect to complete failures. Investigation into the causes of mortality during the first year of seedling establishment is necessary to provide a full understanding of the practices required to successfully establish a stand on an operational level. By increasing the number of landowners who engage in the requisite steps identified, plantation establishment success should be improved.

Directing landowners who recently established plantations to cost-share opportunities specifically designed for subsequent stand tending will likely lead to increased participation in those activities identified as key to success. This study should add clarity to the issue of the importance of appropriate stand management techniques, particularly those which people may be reluctant to employ, such as herbicide application. Given that future demands placed on private forests are sure to increase, effective plantation management presently will help meet those future needs.

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Update on Oak Seed Quality Research: Hardwood Recalcitrant Seeds

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Abstract: In 2 experiments, acorns of cherrybark oak (*Quercus pagoda* Raf.) and water oak (*Q. nigra* L.) were stored at 2 temperatures and 2 moisture contents for 3 years, and acorns of white oak (*Q. alba* L.) and cherrybark oak were desiccated over a span of up to 11 days and examined for physiological and biochemical changes. We found that after 2 years of storage, only cherrybark and water oak acorns that had been stored fully hydrated retained high viability. In addition, those stored at –2 °C (28 °F) were more viable than those stored at 4 °C (39 °F). In the desiccation study, we found rapid decreases in acorn viability, accompanied by changes in the lipid, protein, and carbohydrate fractions. Changes were seen in membrane lipids and proteins in as few as 3 to 4 days of drying, suggesting that the physiological deterioration of these acorns begins relatively soon after shedding. We suggest that all precautions against moisture loss be taken during collection and storage, especially if acorns are not used immediately.

Keywords: acorns, biochemistry, FT-IR, gas chromatography, oaks, recalcitrant seeds, storage

Introduction

Low temperature storage of hardwood seeds has been studied for the last 30 years, yet the biochemical and physiological causes of recalcitrance in tree seeds remain unknown. While orthodox seeds can be dried without damage to moisture contents of less than 12% (fresh weight basis) and stored at low temperatures for long periods of time, recalcitrant seeds cannot (Roberts 1973). Some temperate tree genera with recalcitrant seeds are *Castanea*, *Aesculus*, and some *Acer* and *Quercus*. Sensitive to moisture loss and metabolically active, the acorns of the white oak subgenus Lepidobalanus germinate soon after seed fall and cannot be stored for more than a few months (Rink and Williams 1984). However, acorns of the red oak subgenus Erythrobalanus can be stored for greater than 1 year, although viability loss may be high (Bonner and Vozzo 1987; Connor and Bonner 1999). Hypotheses to explain the physiological basis of seed recalcitrance include: 1) changes in membrane and storage lipids (Pierce and Abdel Samad 1980; Flood and Sinclair 1981); 2) physical disruption of seed membranes (Seewaldt and others 1981); 3) changes in seed proteins and carbohydrates (Finch-Savage and others 1994a,b; Bochicchio and others 1997; Greggains and others 2000); 4) changes in water properties of desiccating seeds (Farrant and others 1985); and 5) aberrant metabolic processes during hydrated storage and as water is lost (Pammenter and others 1994). While the latter hypothesis explains the cause of recalcitrance and is accepted by many researchers, it still does not quantify or define the physiological and biochemical processes responsible. The information given in this paper summarizes the projects underway at the Center for Bottomland Hardwoods Research. The objectives of our current research are: 1) to study the seed storage requirements of various species of hardwoods with recalcitrant seeds; and 2) to examine the effects of storage and desiccation on the biochemistry of recalcitrant seeds.

Materials and Methods

General

Acorns of cherrybark oak (*Quercus pagoda* Raf.), water oak (*Q. nigra* L.), and white oak (*Q. alba* L.) were collected and soaked overnight in tap water to ensure full hydration. Floaters were discarded. Moisture contents of these fresh acorns were determined by drying 2 to 4 samples at 105 °C (221 °F) for 16 to 17 hours. For germination tests, acorns were cut in half horizontally and the seed coat was removed from the half containing the embryo. The acorn was then placed cut-side-down on moist Kimpak and kept under an alternating temperature regime of 20 °C (68 °F) for 16 hours in the dark and 30 °C (86 °F) for 8 hours with light (Bonner and Vozzo 1987). Counts were conducted weekly for 4 weeks.

Storage Studies

Experiment 1—Cherrybark and water oak acorns were collected in 1999 and 2000. Half of the acorns were stored fully hydrated and the other half dried on a lab bench for 48 hours and then stored. Lots consisted of 110 to 120 acorns in 4-mil polyethylene bags stored at either 4 °C (39 °F) in a Lab-Line Ambi-Hi-Low Chamber or at –2 °C (28 °F) in a modified chest freezer. Original percent germinations and moisture content were determined and then tested at yearly intervals. Acorns were germinated as 2 replications of 50 seeds per sampling period and were soaked overnight in tapwater prior to germination testing.

Experiment 2—We used Fourier transform infrared spectroscopy (FT-IR) and gas chromatography (GC) to examine the biochemical changes taking place in desiccating acorns of white oak (*Q. alba* L.) (Connor and Sowa, forthcoming) and cherrybark oak (Sowa and Connor 2003). Collected acorns were soaked in tapwater overnight and then spread on blotter paper in a single layer on a lab bench to dry for up to 11 days. Moisture contents and viability were determined for each experiment performed. Seed samples were collected at regular intervals over the course of the 11-day drying period. At each FT-IR sampling period, transmission spectra were recorded on thin slices of cotyledon and embryonic axes squashes that were placed between CaF_2 windows of a demountable transmission cell. Duplicate samples were analyzed on each sampling day. Additionally, acorns that had been dried were rehydrated overnight and scanned the following day. For each spectrum, 512 scans at 2 per cm resolution were collected. GC analyses were performed on carbohydrate extractions of white oak only. Samples were extracted as detailed in Connor and Sowa (forthcoming) and analyzed on a HP 5890 GC using a Supelco SPB-5 capillary column.

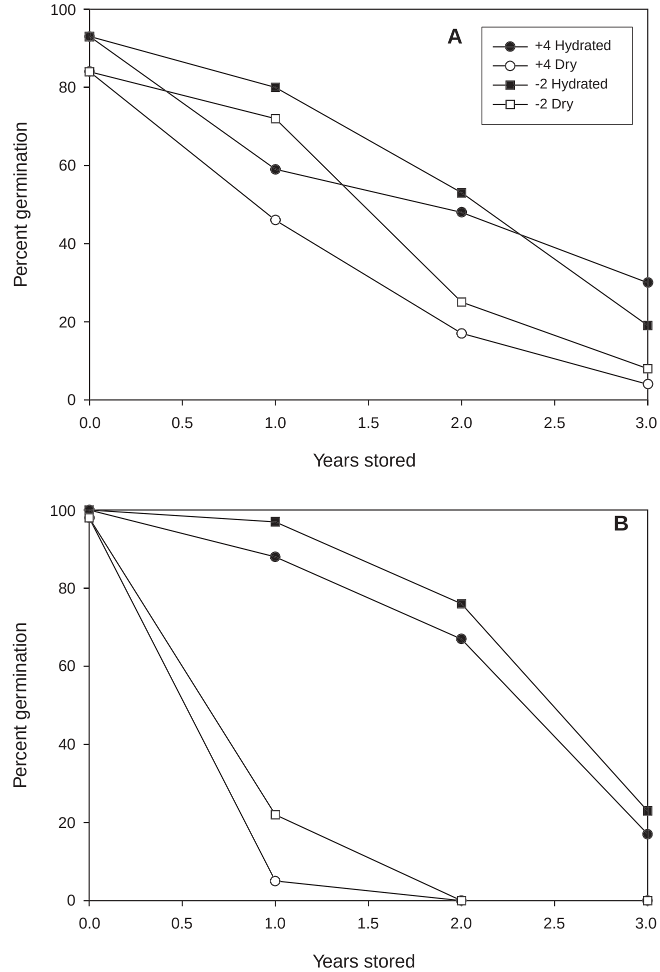

Figure 1—Viability of water oak (A) and cherrybark oak (B) acorns stored at two moisture contents (hydrated or dry) and two temperatures (4 °C [39 °F] or –2 °C [28 °F]) for 3 years.

Results

Experiment 1—Water oak acorn moisture was 30.5% (fresh weight basis) for fully hydrated acorns and 25.6% for those that had dried 48 hours prior to storage. Drying reduced initial viability by 9% (Figure 1A). After 1 year in storage, temperature of storage was significant but seed moisture content was not; seeds stored at –2 °C had a higher viability than those stored at 4 °C. However, after 2 years in storage, the results were reversed; acorn moisture content was significant and temperature of storage was not. Acorns that had been dried prior to storage had lower viability than those stored fully hydrated.

Cherrybark oak acorns had an initial moisture content of 29.6% for fresh acorns and 19.9% for those that had been dried before storage. Drying had little effect on initial viability, reducing it by only 2% (Figure 1B). However, unlike the water oak experiment, temperature of storage was not a significant factor. Only acorns stored fully hydrated retained high viability. In both water oak and cherrybark oak, moisture contents did not change during the course of the experiment.

Experiment 2—Viability declined rapidly in desiccating seeds of both species (Figure 2) and was sensitive to seed moisture content levels of 25 to 30% in white oak and approximately 17% in cherrybark oak. Seed moisture dropped to about 10% after 7 days of drying in white oak and to 12% after 6 days of drying in cherrybark oak.

Phase changes were seen in the membrane lipids of the embryonic axes and cotyledon tissue of both species (Figures 3 and 4). These were exhibited by peak shifts of the symmetric and asymmetric $–CH_2$ vibrations near 2850 and 2910 per cm. As viability was lost, the peaks did not return to their original frequency/bandwidth when rehydrated, indicating that the membrane lipid phase remained less fluid than in the fresh acorns. The fact that changes were seen in membrane lipids in as few as 3 to 4 days of drying suggests that the physiological deterioration of these acorns begins relatively soon after shedding. It was also possible to detect

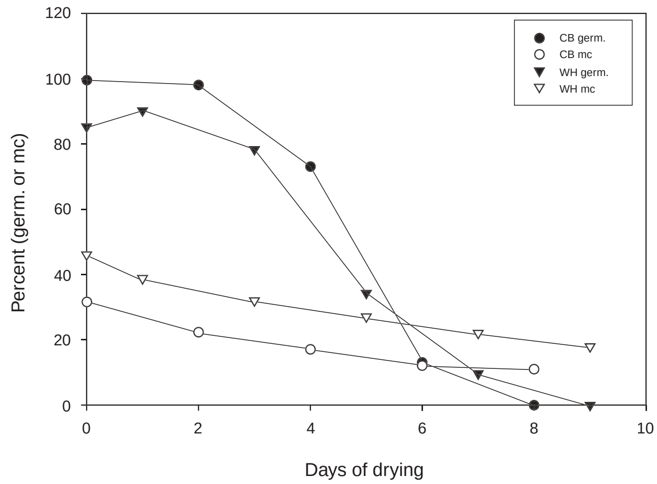

Figure 2—The effects of desiccation on the viability (germ) and moisture content (mc) of cherrybark oak (CB) and white oak (WH) acorns.

differential drying within the acorns (Figure 5). Narrow peak widths and lower peak frequencies indicate dry tissues, while broad peaks indicate hydrated tissues.

Changes in the protein secondary structure, indicated by shifts in the frequency and bandwidth of the amide I and II vibrations near 1650 and 1550 per cm, were also found in drying acorns (Figure 6). FT-IR analyses showed that the loss of protein secondary structure was irreversible; rehydrating the acorns did not restore them to the fresh condition.

GC analyses indicated that while stachyose and raffinose were absent from white oak acorns, there was an abundance of sucrose in both the embryonic axes and cotyledon tissue (Figure 7). Changes in sucrose concentration were not significant until 5 days of drying; then sucrose concentration increased by 3X in the cotyledons and almost 4X in the embryonic axes.

Discussion

In experiment 1, cherrybark and water oak acorns retained high viability for 2 years if stored fully hydrated. While the drying period of 48 hours before storage had little effect on initial viability—reducing germination in water oak acorns by 9% and that of cherrybark oak acorns by only 2%—the damage was evident after 1 year in storage. Water oak acorns stored for 1 year at 4 °C and cherrybark acorns stored for 1 year at either temperature had significant losses in viability if dried before storing. The result of a seemingly small drop in moisture content on long-term storage viability emphasizes the importance of proper seed collection and handling procedures. High moisture content must be maintained in recalcitrant seeds in order to retain high seed viability. We strongly suggest that all precautions against moisture loss be taken during collection and storage, especially if acorns are not used immediately. Otherwise, severe losses in seed quality can occur. Orchard managers and seed companies must place emphasis on

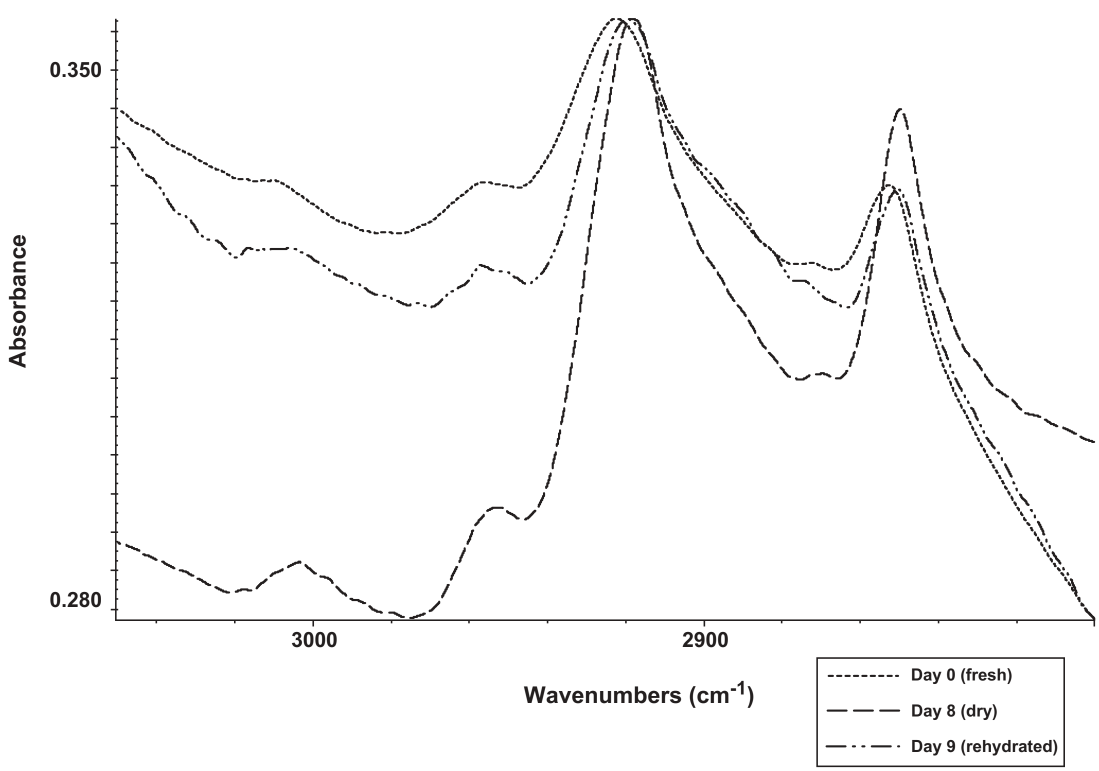

Figure 3—Membrane lipid vibrations in cherrybark oak embryonic axes at day 0 (fresh), day 8 (dry), and day 9 (rehydrated). Peak frequencies are at 2852.2, 2849.7, and 2850.3 per cm.

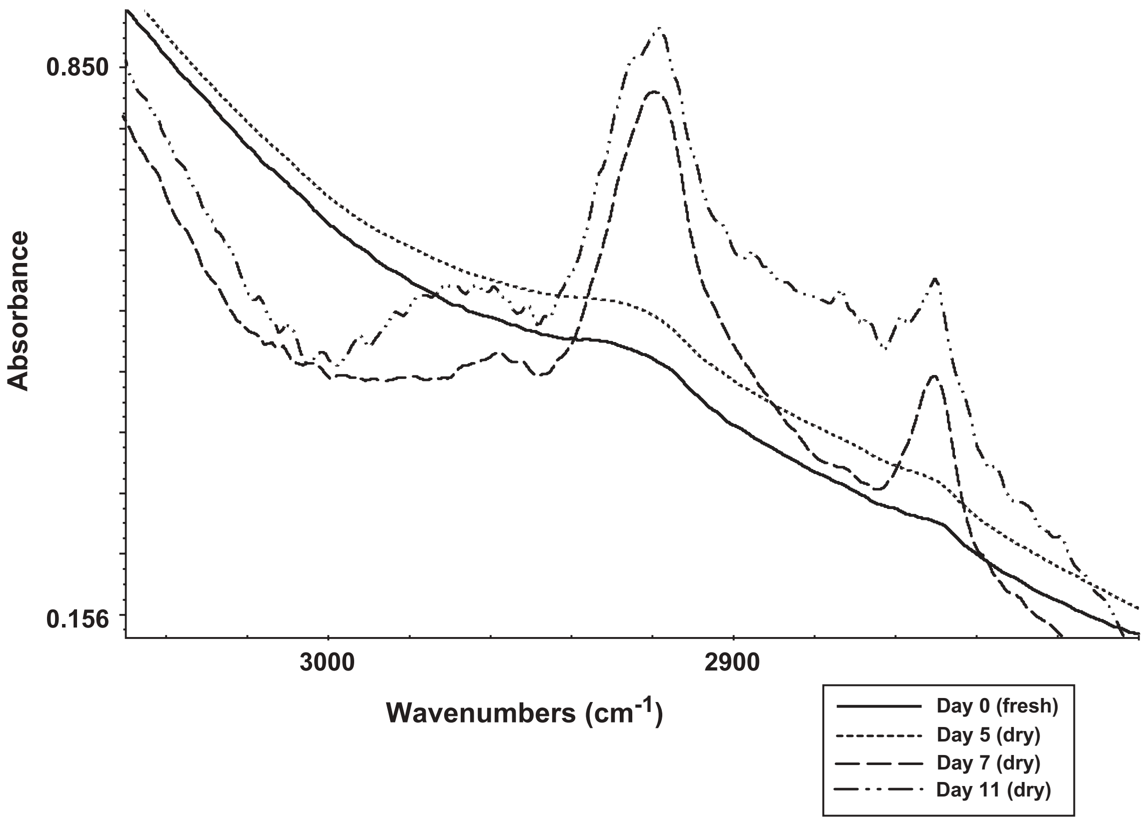

Figure 4—Transmission IR spectra of lipid membranes of rehydrated white oak embryonic axes. Membrane lipid vibrations in fresh (day 0) axes and those dried 5, 7, and 11 days.

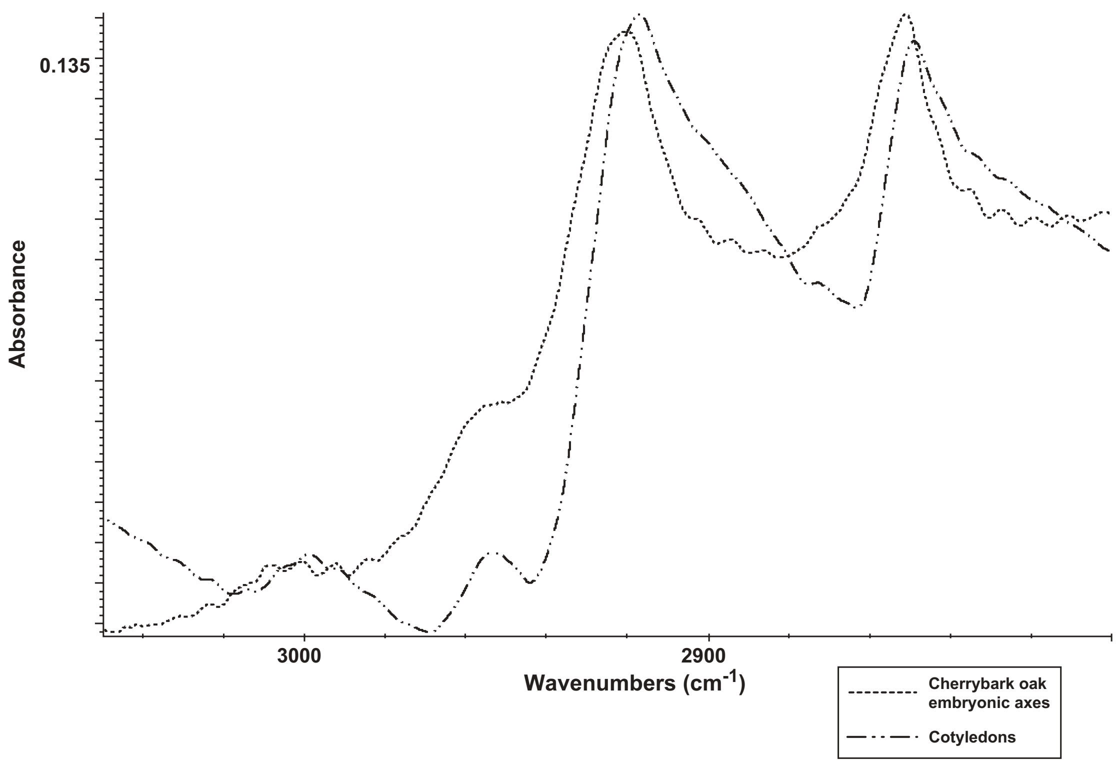

Figure 5—Membrane lipid vibrations in day 4 (dry) cherrybark oak embryonic axes and cotyledons. Narrow peaks in the cotyledons emphasize differential drying.

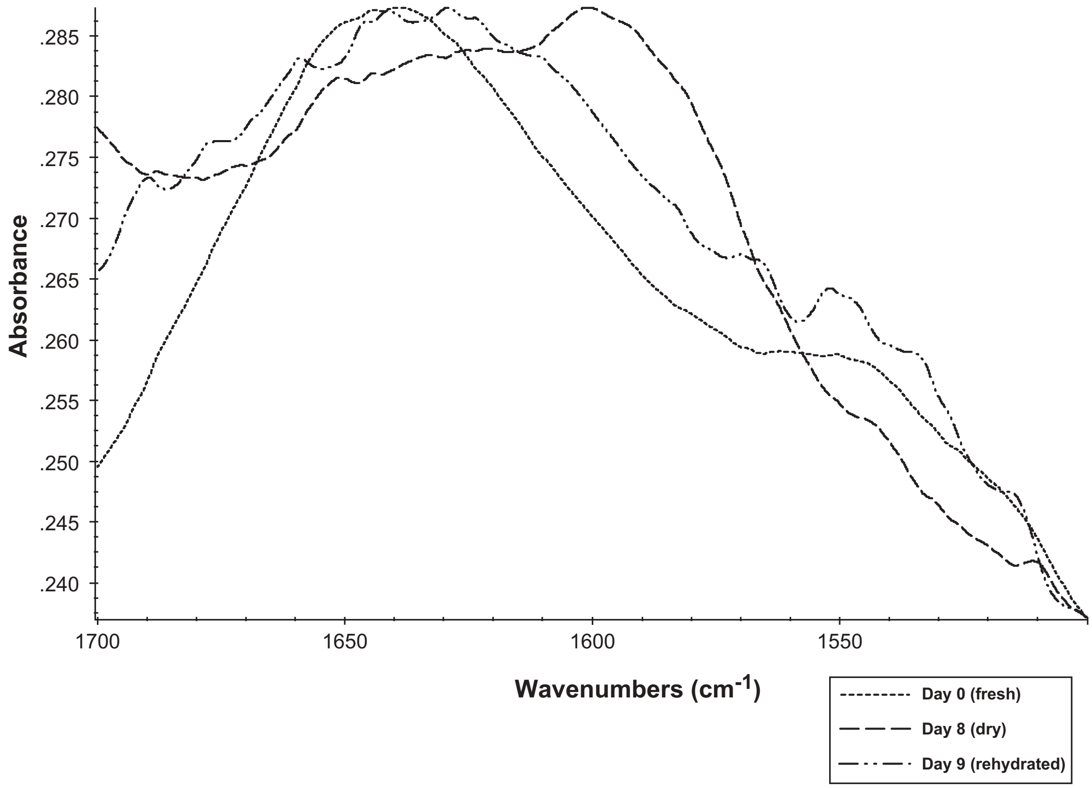

Figure 6—Amide I and II vibrations representing protein secondary structure in fresh (day 0), day 8 (dry), and day 9 (rehydrated) cherrybark oak embryonic axes.

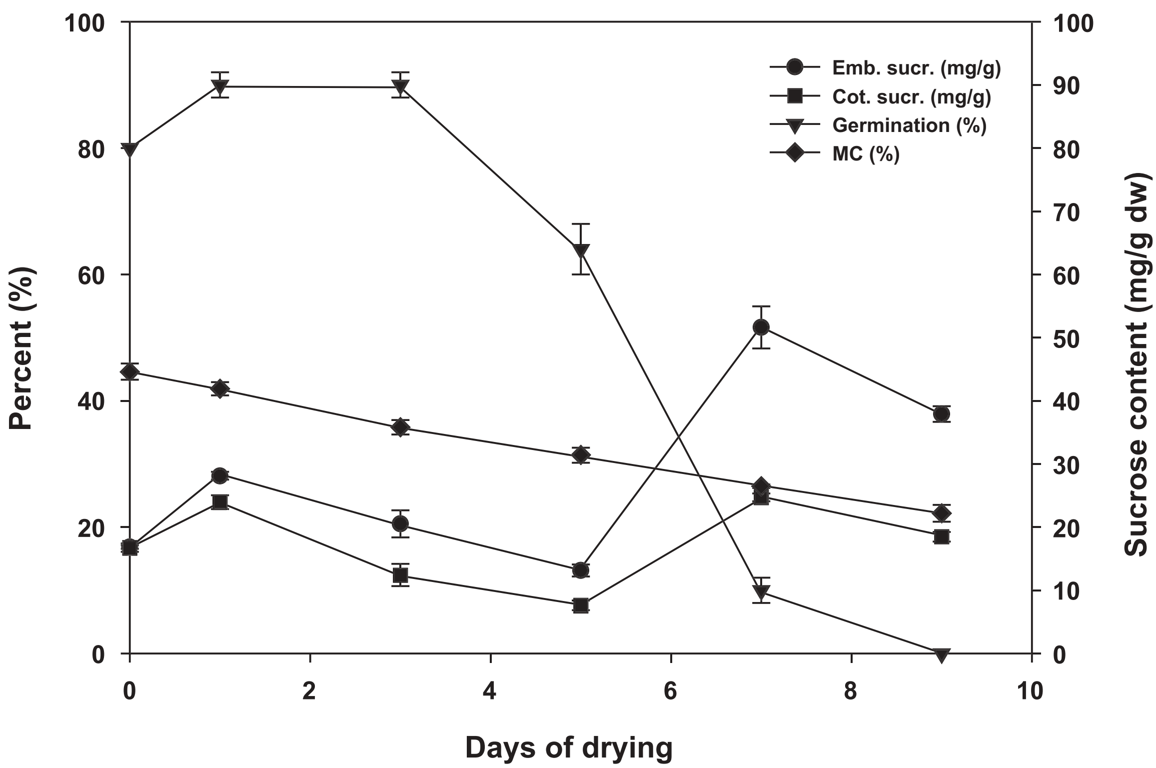

Figure 7—Germination, moisture content (mc), and sucrose content (sucr) in desiccating white oak embryonic axes (emb) and cotyledons (cot). Data from gas chromatography experiments.

careful handling of acorns during the collection process. The sooner acorns can be collected after dropping from the tree, and placed under refrigeration, the higher the probability of successful long-term (1-year) storage. In years with high temperatures and low rainfall during acorn drop, collection in the field must be prompt to ensure that acorn moisture content does not fall below the critical level or that acorns are not put under too much moisture stress before they reach a storage facility. Red oak acorns, as a whole, generally survive for 1 year in storage. Cherrybark oak acorns that dried for only 2 days in the laboratory had less than 25% viability after 1 year of storage under ideal conditions, and were dead after 2 years; those stored at high moisture contents retained at least 67% viability.

Results of experiment 2 emphasized the effects of short-term drying on viability. In cherrybark oak acorns, an extremely rapid decline in germinability occurred between days 4 and 6; the transition point occurred somewhere near a seed moisture content of 17%. We found similar effects of desiccation in white oak acorns. In the FT-IR and GC studies, changes were taking place in the storage and membrane lipids, in the protein secondary structure, and in the carbohydrates during the desiccation process. Membrane lipids changed phase from liquid crystalline to gel upon drying and did not recover when acorns were rehydrated by soaking in water. This structural change ultimately results in acorn mortality, since cell contents can pass indiscriminately through the leaky membranes. Despite the fact that white oak embryonic axes maintain a fairly high moisture content through the desiccation experiment, damage ultimately becomes irreparable. In all species studied, structural damage was seen first in the cotyledon tissue. In addition, the increasing sucrose content in the white oak embryonic axes, coupled with declining acorn viability, suggests that the sucrose is no longer being used for growth and development and/or that starch is being broken down by enzymatic activity in the deteriorating seeds.

Storing seeds fully hydrated has many drawbacks. Seeds continue to respire and can germinate even when stored under low temperatures. Insects remain active, and fungal damage can also occur. Thus, the probability of seed deterioration during storage increases. As our experiments have shown, the acorns of cherrybark oak, water oak, and white oak will decline under hydrated storage. They are metabolically active and can lose viability when stored for longer than 2 years. If subjected to desiccation before storage, however, the situation becomes even more untenable. Shifts in membrane lipids from the liquid-crystalline to the gel phase, changes in protein secondary structure, and cessation of growth and development all occur in desiccating acorns. Thus, while far from ideal, storing acorns of cherrybark oak, water oak, and white oak fully hydrated is at this time the best possible option.

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How Acorn Size Influences Seedling Size and Possible Seed Management Choices

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Keywords: seed vigor, seed sizing, *Quercus rubra*, *Quercus alba*

Introduction

Seed size has been found to influence seed vigor and seedling size in many plants. Some nurseries size acorns for the purpose of producing more uniform seedlings. No carefully constructed data set has been published that quantifies the advantages of this practice. Therefore, a study was set up to do this; initial results are presented in this paper.

Methods

Four state-owned nurseries were used as test sites: Vallonia State Nursery and Jasper-Pulaski State Nursery (IDNR) in Indiana, Wilson State Nursery (WDNR) in Wisconsin, and Penn Nursery (PDCNR) in Pennsylvania. Red oak (*Quercus rubra*) was planted at each of the 4 nurseries. White oak (*Q. alba*) was planted at Vallonia and Penn. Each nursery provided one of its own seed lots for each species planted. This gave a total of 4 red oak seed lots and 2 white oak seed lots. Prior to planting, the acorns were floated and sized with round-hole screens into as many sizes as were possible using the following screen sizes: 44, 46, 48, 50, 52, 54, 56, 58, 60. Acorns were planted by hand in 3-ft (1-m) long plots, with 24 acorns in each of 5 rows to obtain (assuming a survival factor of 0.80) a seedling density of 8 seedlings/ft^2 (86 seedlings/m^2). A 1-ft (0.3-m) plot was marked in the center of the 3-ft plot with a small piece of flagging fastened to the ground by piercing it through the center with a 12d nail. This center 1 ft (0.3 m) was the measured plot; the outer 2 ft (0.6 m) served as borders from the adjoining plots. Plots were contiguous down the bed. The experimental design was a randomized complete block. Cultural conditions were the same as production stock, with the exception that there was no top clipping. At lifting, the seedlings were mechanically undercut and lifted by hand with each plot being placed into a separate bag. The following morphological measurements were made on every lifted seedling: stem diameter 25 mm (1 in) above the root collar to the nearest mm, total height in cm, fresh weight in grams, and root volume in cc. Root volume was determined using the water displacement method. A bucket of water was placed on a scale. The bucket contained a chamber held free from the sides and bottom of the bucket by a support rod held by a ring stand. The reaction force to the bouyant force generated by submerging the seedlings roots was measured on the scale and used as the root volume. Plot means were analyzed by simple linear regression.

Results

There were 10 sizes of red oak at the Jasper-Pulaski Nursery and 8 sizes at the Wilson Nursery. Seedlings were not available from the Penn Nursery due to its short growing season; however, the seedlings grew well and will be examined fall 2003. The first summer at Vallonia was very hot and dry, rendering the experiment there unusable.

Regressions of the plot means were significant for all measured variables when regressed against acorn diameter (Figures 1 through 4). As acorn size increased, the average size of the seedling increased for all 4 morphological traits measured. Wilson Nursery provided the one exception in that the largest size acorns produced small seedlings. This has no apparent explanation. The data was very similar at both nurseries, so only the graphs from Jasper-Pulaski are shown here.

Discussion and Conclusions

This study demonstrated very clearly that the larger the acorn, the larger the average seedling would be in diameter, height, fresh weight, and root volume. Acorn sizing appears to be one tool the nursery manager can use to produce larger seedlings.

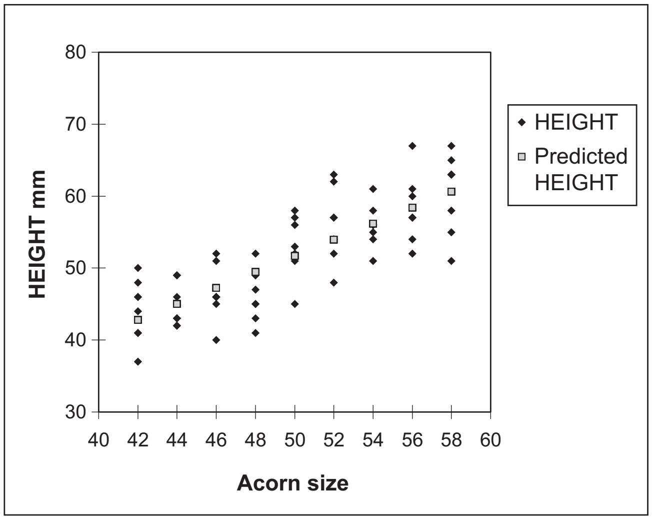

Figure 1—Seedling height versus acorn size at Jasper-Pulaski Nursery.

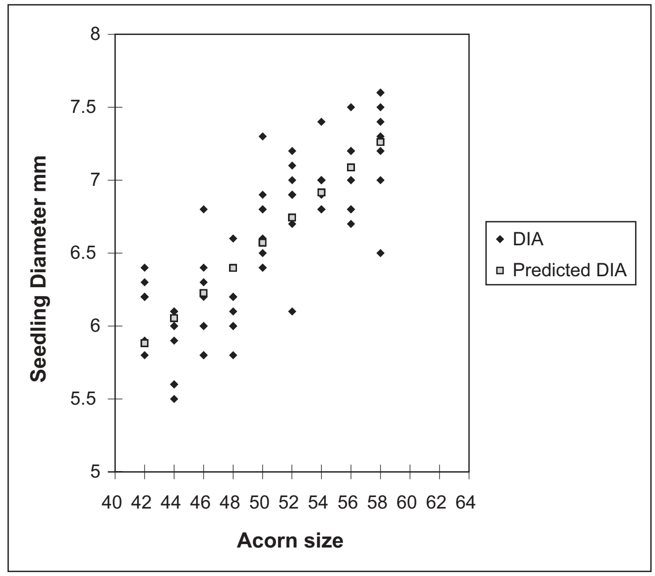

Figure 2—Seedling diameter versus acorn size at Jasper-Pulaski Nursery.

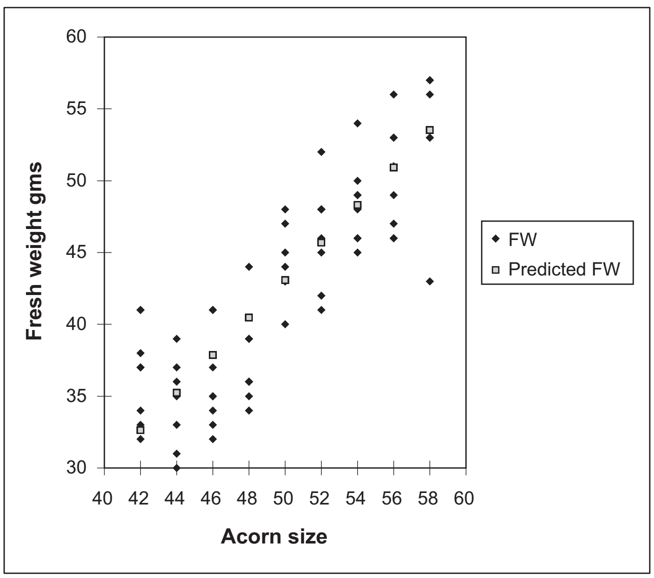

Figure 3—Seedling fresh weight versus acorn size at Jasper-Pulaski Nursery.

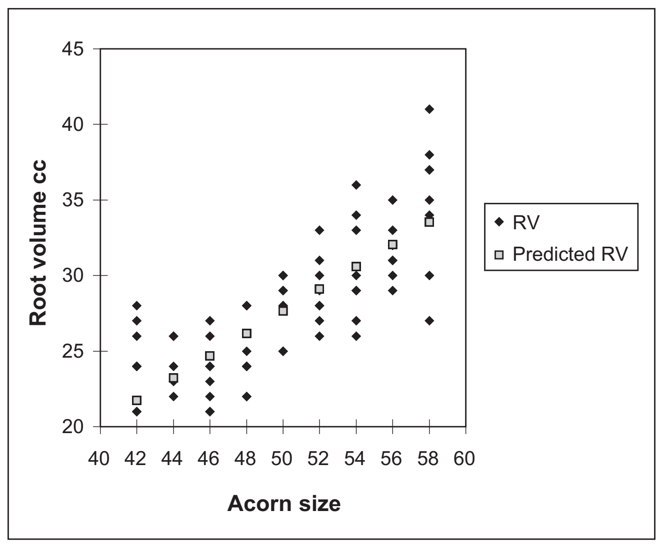

Figure 4—Seedling root volume versus acorn size at Jasper-Pulaski Nursery.

However, discarding small acorns should not be practiced unless there is good genetic evidence to demonstrate the practice is not discarding whole families with possible good growth potential. Even the small acorns produced seedlings of acceptable size, although cull rates appeared to be higher in the small acorn classes. Cull rates have not yet been calculated from the data.

Acorn sowing density possibly needs to be matched to acorn size to optimize growth rate. It might be that small acorns produce fewer seedlings with the potential to make grade. If the better growers in the small acorn size can outgrow the poor growers sufficiently well, then a higher sowing density might give more plantable seedlings per square unit of bed. In the other direction, a lower sowing density for large acorns could produce even a larger seedling in 1 season.

An additional strategy may well be to grow the small acorns as 2+0 seedlings while the larger acorns could go for 1+0 seedlings. Such a strategy would allow for extending seed supplies over several crops of seedlings. This would essentially be storing acorns "on the stump." It would be necessary to determine if the smaller seedlings would eventually catch up in growth potential to the large seedlings before this strategy is adopted.

Panel Discussion: Goals in Supplying Tree Seed

Rob Lovelace
Judy Lovelace

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Keywords: seed sales, seed source, seed collection, seed quality

Introduction

Collection of tree seeds for nursery use involves a number of key decisions and goals in order to provide high quality, premium seeds for use in reforestation.

Quality

The following factors must be considered to ensure high quality seed: 1) selection of genetic makeup of plant material harvested; 2) care of harvested material while preparing for cleaning; 3) proper selection and method of seed cleaning; 4) sorting seeds into lots according to size (sizer); and 5) sorting by density after sized (gravity table).

Consistency

It is necessary to know when conditions are right to harvest seeds. If collection occurs too early, low viability of seeds may result. If collection occurs too late, competing factors will influence quantities of seeds collected. Competition includes wildlife, weather, and other collectors.

Good communication is extremely important. Close contact with customers on current conditions of seeds must be maintained.

Seeds should be cleaned with the same cleaning processes year after year.

Reliability

Knowledge of the market conditions is required for success in supplying seeds. Potential customers/uses may include: 1) private nurseries; 2) state nurseries; 3) export market; and 4) direct seeding projects.

Being dependable consists of balancing our demands for seeds between quality, quantity, price, and the needs of the 4 groups listed above.

Price/Value

The correlation between buyer, seller, quantities, and quality will set the price/value of seeds. In a market that has no labeling requirements as to purity, moisture content, or percentage of foreign material, we need to make sure that price equals value, and that value matches price.

In order to ensure price equals value, a number of measures can be taken, including: 1) conducting a cutting test, with the price based on the percentage of sound seeds; 2) avoiding moisture content issues by purchasing seeds according to volume rather than weight; and 3) purchasing seeds from dependable, well-established sources.

Panel Discussion: Tree Seed Collection and Direct Seeding in Illinois

Tom Ward

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Keywords: hardwood species, seed storage

The Nature Conservancy in southern Illinois has used direct seeding for forest regeneration since 1989. The Association of Illinois Soil and Water Conservation Districts (AISWCD) held its first direct seeding workshop in 1996. It was in the fall of 1998, however, that Illinois conservationists began to consider direct seeding as a way to accelerate reforestation of riparian buffers. In early 1999, the Forestry Committee of the AISWCD formed a 4-person Direct Seeding Subcommittee. Based on 5 years of work, this subcommittee has published the 150-page *Illinois Direct Seeding Handbook*, conducted 10 workshops and field trips, and distributed seed collection equipment to a 25-county network of SWCDs.

The rate of direct seeding in Illinois has increased from a few dozen acres to about 3,200 ac (about 1,300 ha) in 2001. Interest in direct seeding has been driven by a very large enrollment in the Riparian Forest Buffer practice, which is available through the Conservation Reserve Program (CRP). Between 1997 and 2003, about 93,000 ac (37,635 ha) have been enrolled in Riparian Forest Buffers in CRP, with an additional 20,000 ac (8,100 ha) in the Illinois River Conservation Reserve Enhancement Program (CREP). Due to very high demand, Illinois has faced a chronic shortage of bottomland hardwood seedlings for reforestation of floodplain sites. Compounding this problem is the fact that tree planting is typically done between February and May, when floodplain sites are often underwater or too muddy to plant. Direct seeding utilizes a readily available local resource, Illinois tree seeds, and is best suited to fall planting when floodplains are accessible.

From the beginning, the Direct Seeding Subcommittee has sought to minimize competition for seeds between direct seeding and tree nurseries by promoting increased seed collection. The *Illinois Direct Seeding Handbook* emphasizes tree identification, seed collection, handling, and storage. In the training and workshops on direct seeding, an emphasis is placed on collecting high quality seeds and maintaining seed viability through proper handling and storage.

There have been some challenges in expanding the use of direct seeding. Variability of seed crops has made it necessary to modify species lists in direct seeding plans. In 2001, the only bottomland species available in abundance in central Illinois was bur oak. Last year (2002) was only somewhat better, with swamp white oak (SWO) the most abundant. The length of the seed collection season has made it necessary to store some species while waiting for others to mature. SWO, for example, may begin dropping in early September while pin oak and shellbark hickory may not be available until the end of October. Seed planting may be delayed until November, waiting for late-dropping species to become available. If there is a wet fall and/or an early winter, there may be a very short planting season and a lot of leftover seeds. Brief planting windows may occur in December, January, and February, but favorable winter weather may not occur every year. Large quantities of seeds are needed for direct seeding, and storage space, especially refrigerated storage, may be limited or expensive. Good success has been reported in storing seeds over winter for spring planting if properly handled. Even species in the white oak group, including *Quercus alba*, but especially SWO and bur oak, have been successfully stored for planting in March or April.

A very important tool has been the Direct Seeding Web site, http://www.directseeding.org. Launched in 2001, the purpose of the Web site is to bring together those who have tree seeds with those who need them. Thirty-nine tree seed vendors are presently listed, and there is a classified ad feature to highlight the seeds that are presently available or needed. Other features of the Web site include tree seed crop reports, seed collection equipment, information on tree identification, seed biology, seed collection, and seed storage.

Panel Discussion: Seed Supply Issues for Vallonia Nursery

Robert Hawkins
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Keywords: seedling, seed source, seed collection

Vallonia Nursery

Setting our production goals by year is based on a forecast for seedling demand.

Seeds Needed

The amount of good seeds needed is based on the following factors (Figure 1):

1. Recovery factors from previous years.
2. Sowing rates.
3. Estimated good seeds per pound (based on 6- to 7-year data).
4. Setting quotas for each nursery/statewide to meet our goals.

This is for the seeds we know we can purchase from local seed vendors throughout Indiana. Seeds that are historically purchased from vendors outside the state are purchased in a different manner.

Typically, with the number of collectors that participate in our Seedbuy Program, only the scarcity of the seeds in the areas of collection would keep us from meeting our seed quotas within the state. Minor adjustments are made during the collection process to the individual quotas if a species is abundant and another is scarce. Revisions are made based upon site locations as to where the trees typically are grown. Our overall production goal is achieved, with slight changes made to the original goal of individual species.

Seed Prices

Prices for good seeds are based on the following factors (Figure 2):

1. Previous years' prices.
2. Seed abundance or scarcity.
3. Going rates.
4. Internal budgets.

Statewide Collection

Purchasing regionally adapted seeds from local collectors throughout the state helps to maintain the genetic diversity of the nursery planting stock. Historically, seeds from diverse sources were collected by the state's district foresters. Recently, most seeds have been purchased from sources closer to the nurseries.

					SEEDLING	SEEDLING	EMERGED					
VALLONIA				SEED TO	TO	TO	TO					
CODES PROGRAM	OK			SEEDLING	SEEDLING	SEEDLING	SALEABLE		TARGET	GOOD	TOTAL	ESTIMATED
TODAY IS:	PRODUCTION	PRODUCTION	PRODUCTION	RECOVERY	RECOVERY	RECOVERY	SEEDLING	SOWING	DENSITY	SEED	GOOD	POUNDS
29-Jul-03	GOAL FOR	GOAL FOR	GOAL FOR	FACTOR	FACTOR	FACTOR	RECOVERY	RATE	EMERGED	NEEDED	SEED	OF SEED
	1-0	2-0	3-0	FOR 1-0	1-0 TO 2-0	2-0 TO 3-0	FACTOR	1-0	SEEDLINGS	1-0	NEEDED	NEEDED
SEASON TOTAL	3,968,000	590,000	200,000							11,381,904	13,688,685	90,122
SPECIES												
VIRGINIA PINE 1-0	40,000	0	0	20%	100%	100%	60%	45	9	333,333	333,333	9
PITCH X LOBLOLLY F2 1-0	50,000	0	0	50%	100%	100%	65%	18	9	153,846	153,846	6
BLACK CHERRY 1-0	100,000	0	0	40%	100%	100%	70%	20	8	357,143	357,143	291
BLACK GUM 1-0	40,000	0	0	60%	100%	100%	80%	15	9	83,333	83,333	89
BLACK OAK 1-0	90,000	0	0	80%	100%	100%	70%	9	7	160,714	160,714	1,256
BLACK WALNUT 1-0	240,000	0	0	60%	100%	100%	80%	6	4	500,000	500,000	27,277
BUR OAK 1-0	257,000	0	0	70%	100%	100%	70%	8	6	524,490	524,490	15,483
CHERRYBARK OAK 1-0	100,000	0	0	60%	100%	100%	80%	9	5	208,333	208,333	762
CHINKAPIN OAK 1-0	40,000	0	0	60%	100%	100%	75%	9	5	88,889	88,889	692
GREEN ASH 1-0	166,000	0	0	70%	100%	100%	80%	15	11	296,429	296,429	32
PECAN 1-0	90,000	0	0	50%	100%	100%	80%	11	6	225,000	225,000	1,754
PERSIMMON 1-0	100,000	0	0	75%	100%	100%	80%	10	8	166,667	166,667	214
PIN OAK 1-0	105,000	0	0	75%	100%	100%	90%	9	7	155,556	155,556	702
RED OAK 1-0	300,000	0	0	80%	100%	100%	70%	9	7	535,714	535,714	8,373
RIVER BIRCH 1-0	60,000	0	0	20%	100%	100%	80%	35	7	375,000	375,000	3
SCARLET OAK 1-0	60,000	0	0	80%	100%	100%	75%	8	6	100,000	100,000	872
SHUMARD OAK 1-0	110,000	0	0	80%	100%	100%	80%	8	6	171,875	171,875	2,514
SILVER MAPLE 1-0	40,000	0	0	50%	100%	100%	70%	14	7	114,286	114,286	87
SWAMP CHESTNUT OAK 1-0	150,000	0	0	85%	100%	100%	80%	9	8	220,588	220,588	5,152
SWAMP WHITE OAK 1-0	150,000	0	0	80%	100%	100%	80%	9	7	234,375	234,375	3,154
SWEETGUM 1-0	60,000	0	0	30%	100%	100%	60%	70	21	333,333	333,333	13
SYCAMORE 1-0	75,000	0	0	25%	100%	100%	80%	40	10	375,000	375,000	4
TULIPTREE 1-0	300,000	0	0	35%	100%	100%	75%	18	6	1,142,857	1,142,857	2,264
WHITE ASH 1-0	200,000	0	0	40%	100%	100%	80%	25	10	625,000	625,000	125
WHITE OAK 1-0	300,000	0	0	65%	100%	100%	75%	9	6	615,385	615,385	7,836
OVERCUP OAK 1-0	90,000	0	0	65%	100%	100%	80%	9	6	173,077	173,077	2,253
SHINGLE OAK 1-0	30,000	0	0	75%	100%	100%	75%	9	7	53,333	53,333	229
BALD CYPRESS 1-0	100,000	0	0	25%	100%	100%	85%	35	9	470,588	470,588	456
CHESTNUT OAK 1-0	40,000	0	0	80%	100%	100%	75%	9	7	66,667	66,667	1,722
KENTUCKY COFFEE TREE 1-0	30,000	0	0	70%	100%	100%	70%	8	6	61,224	61,224	426
BUTTONBUSH 1-0	20,000	0	0	25%	100%	100%	50%	28	7	160,000	160,000	2
ELDERBERRY 1-0	25,000	0	0	13%	100%	100%	65%	35	5	295,858	295,858	7
FLOWERING DOGWOOD 1-0	100,000	0	0	35%	100%	100%	80%	25	9	357,143	357,143	376
HAZELNUT 1-0	30,000	0	0	50%	100%	100%	80%	15	8	85,714	85,714	387
REDBUD 1-0	70,000	0	0	60%	100%	100%	70%	15	9	166,667	166,667	17
SILKY DOGWOOD 1-0	50,000	0	0	60%	100%	100%	80%	12	7	104,167	104,167	22
GRAY DOGWOOD 1-0	50,000	0	0	30%	100%	100%	70%	28	8	238,095	238,095	54
SPICEBUSH 1-0	20,000	0	0	65%	100%	100%	50%	12	8	61,538	61,538	41
BLACK CHOKEBERRY 1-0	60,000	0	0	8%	100%	100%	85%	80	6	882,353	882,353	6
SMOOTH SUMAC 1-0	10,000	0	0	50%	100%	100%	80%	20	10	25,000	25,000	1
COMMON CHOKECHERRY 1-0	20,000	0	0	30%	100%	100%	80%	20	6	83,333	83,333	16

Figure 1—Example of calculations for seeds needed by species for Vallonia Nursery.

CODE	SPECIES	TOTAL GOOD SEED NEEDED	TOTAL POUNDS NEEDED	SEEDBUY GOOD SEED NEEDED	SEEDBUY POUNDS NEEDED	SEEDBUY UNIT PRICE	ADJUSTMENT TO VALLONIA SEED NEEDED FOR OTHER NURSERY	GOOD SEED PER POUND
	SEASON TOTALS	13,688,685	90,122	5,791,464	54,006	0	(63,000)	
1.008	WHITE PINE 1-0 FOR 3-0	653,595	30	0	0	$0.00000	0	21,601
1.018	NORWAY SPRUCE 1-0 FOR 2-0	520,833	10	0	0	$0.00000	0	51,680
1.021	WHITE PINE 1-0 FOR 2-0	882,353	45	0	0	$0.00000	0	19,459
1.089	SHELLBARK HICKORY 1-0 FOR 2-0	138,889	4,755	138,889	4,755	$0.03000	0	29
1.144	SHAGBARK HICKORY 1-0 FOR 2-0	0	0	50,000	596	$0.02000	70,000	84
1.280	PAWPAW 1-0 FOR 2-0	111,111	302	111,111	302	$0.02000	0	369
29.000	VIRGINIA PINE 1-0	333,333	9	0	0	$0.00000	0	38,992
31.000	PITCH X LOBLOLLY F2 1-0	153,846	6	0	0	$0.00000	0	27,864
42.000	BLACK CHERRY 1-0	357,143	291	584,143	475	$0.00900	237,000	1,229
43.000	BLACK GUM 1-0	83,333	89	83,333	89	$0.01000	0	936
45.000	BLACK OAK 1-0	160,714	1,256	135,714	1,061	$0.01250	0	128
46.000	BLACK WALNUT 1-0	500,000	27,277	300,000	16,366	$0.01071	0	18
48.000	BUR OAK 1-0	524,490	15,483	74,490	2,199	$0.03000	(300,000)	34
49.000	CHERRYBARK OAK 1-0	208,333	762	0	0	$0.00000	0	273
51.000	CHINKAPIN OAK 1-0	88,889	692	58,889	459	$0.02000	0	128
55.000	GREEN ASH 1-0	296,429	32	246,429	26	$0.00200	0	9,354
58.000	PECAN 1-0	225,000	1,754	0	0	$0.00000	0	128
59.000	PERSIMMON 1-0	166,667	214	146,667	188	$0.01000	(20,000)	780
60.000	PIN OAK 1-0	155,556	702	140,556	634	$0.01200	0	222
63.000	RED OAK 1-0	535,714	8,373	460,714	7,201	$0.01250	0	64
64.000	RIVER BIRCH 1-0	375,000	3	(0)	(0)	$0.00000	0	138,463
67.000	SCARLET OAK 1-0	100,000	872	(0)	(0)	$0.01250	0	115
68.000	SHUMARD OAK 1-0	171,875	2,514	11,875	174	$0.02500	0	68
69.000	SILVER MAPLE 1-0	114,286	87	0	0	$0.00000	0	1,315
71.000	SWAMP CHESTNUT OAK 1-0	220,588	5,152	220,588	5,152	$0.02500	0	43
72.000	SWAMP WHITE OAK 1-0	234,375	3,154	59,375	799	$0.03000	(50,000)	74
73.000	SWEETGUM 1-0	333,333	13	47,619	2	$0.00000	0	25,111
74.000	SYCAMORE 1-0	375,000	4	(53,571)	(1)	$0.00000	0	86,907
75.000	TULIPTREE 1-0	1,142,857	2,264	842,857	1,670	$0.01000	0	505
76.000	WHITE ASH 1-0	625,000	125	575,000	115	$0.00200	0	4,995
77.000	WHITE OAK 1-0	615,385	7,836	615,385	7,836	$0.01250	0	79
79.000	OVERCUP OAK 1-0	173,077	2,253	173,077	2,253	$0.02000	0	77
80.000	SHINGLE OAK 1-0	53,333	229	8,333	36	$0.01250	0	233
83.000	BALD CYPRESS 1-0	470,588	456	0	0	$0.00000	0	1,032
84.000	CHESTNUT OAK 1-0	66,667	1,722	36,667	947	$0.01250	0	39
92.000	KENTUCKY COFFEE TREE 1-0	61,224	426	0	0	$0.00000	0	144
206.000	BUTTONBUSH 1-0	160,000	2	0	0	$0.00000	0	81,180
211.000	FLOWERING CRABAPPLE 1-0	0	0	0	0	$0.00000	0	48,432
214.000	ELDERBERRY 1-0	295,858	7	0	0	$0.00000	0	42,303
216.000	FLOWERING DOGWOOD 1-0	357,143	376	357,143	376	$0.01000	0	950
217.000	HAZELNUT 1-0	85,714	387	45,714	206	$0.02000	0	221
219.000	REDBUD 1-0	166,667	17	66,667	7	$0.00100	0	9,565
220.000	SILKY DOGWOOD 1-0	104,167	22	104,167	22	$0.00500	0	4,794
227.000	GRAY DOGWOOD 1-0	238,095	54	88,095	20	$0.00500	0	4,408
231.000	SPICEBUSH 1-0	61,538	41	61,538	41	$0.00500	0	1,506
259.000	BLACK CHOKEBERRY 1-0	882,353	6	0	0	$0.00000	0	137,340
282.000	SMOOTH SUMAC 1-0	25,000	1	0	0	$0.00000	0	20,432
283.000	COMMON CHOKECHERRY 1-0	83,333	16	0	0	$0.00000	0	5,376

Figure 2—Example of seed pricing by species for Vallonia Nursery.

Pros

- Adds diversity to seed supply.
- Expands base of local collectors.

Cons

- Program costs.
- Generating interest.
- Species identification.
- Communication/program administration.

Inhouse Collection

Planting grafted clones or seedling progeny from "select" parent trees into seed orchards and managing them for optimal seed production allows us to control the quality and cost of the seed supply. Department of Forestry staff and Department of Corrections inmates collect seeds from established orchards and heavily rogued natural stands.

Pros

- Genetically improved stock from seed orchards.
- Ability to control seed quality.
- Lower seed cost (potentially).

Cons

- Irregular cropping cycles in orchards.
- Limited availability of laborers or inmates during busy season.
- Higher seed cost (potentially).

Commercial Purchase

Working with multiple suppliers allows us to identify seed sources and seed collection zones that are appropriate for planting in Indiana's nurseries.

Pros

- Diverse species availability.
- Competitive prices.
- Availability during local crop failures.

Cons

- Inappropriate seed sources.
- Frequently delayed deliveries.
- State government purchasing constraints.

Using Electrolyte Leakage for Evaluating Hardwood Seedling Cold Hardiness

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Abstract: This paper describes the use of electrolyte leakage (EL) from stem tissue as a potential method for assessing cold hardiness of hardwood seedlings. The EL method has seen little use with North American hardwoods, but has successfully predicted conifer hardiness in both controlled and operational settings and has been used experimentally on hardwoods in Europe. Three species of hardwoods—northern red oak (*Quercus rubra* L.), black walnut (*Juglans nigra* L.), and black cherry (*Prunus serotina* Ehrh.)—were evaluated for hardiness at 4 temperatures (3, –10, –20, –40 °C [37, 14, –4, –40 °F]) after being subjected to 3 storage regimes (freezer, cooler, ambient) of varying duration. Higher EL values at lower temperatures and longer durations represent an increase in cell damage and loss of hardiness. For all species, an increase in EL over time (storage duration) corresponded to a decrease in the number of days required for budbreak under greenhouse conditions. EL levels did not appear to be related to height growth after 3 months. The EL trends were similar for all species and storage temperatures, while the 3 species exhibited differing responses to storage temperatures when placed in a greenhouse. The data presented here is preliminary. Further research is needed to gauge the effectiveness of EL as a predictor of seedling hardiness and quality for commonly produced hardwoods.

Keywords: seedling quality, electrolytes, budbreak, freezing, *Quercus rubra*, *Juglans nigra*, *Prunus serotina*

Introduction

Testing cold hardiness is an important component of hardwood seedling quality assessment programs. Cold hardiness provides a measure of dormancy status (Ritchie 1984), predicts the ability to tolerate stresses associated with lifting, storing, and planting (O'Reilly and others 1999), and provides an indication of field performance potential (Pardos and others 2003). Physiological methods of testing cold hardiness can be rapid (McKay 1992), allowing for timely decisions in nursery management systems. All phases of hardwood seedling production and establishment will benefit from further cold hardiness and quality assessment research.

Many methods have been employed for evaluating hardiness of plants. Visual methods, such as whole plant freeze tests and shoot tissue browning, have been effective (Timmis 1976; Liu and others 1998), but are more time consuming. Water relations (Ameglio and others 2001), bud mitotic activity (Calme and others 1994), abscisic acid concentration (Li and others 2003), soluble sugar concentration (Tinus and others 2000), and chlorophyll fluorescence (Rose and Haase 2002) are among the many physiological indicators that have been used on conifers. Measurement of these indicators, while more rapid, has seen limited application to hardwood forestry. The electrolyte leakage (EL) method was chosen for this study. It has been used extensively in conifer research and applications, where it was shown to be a useful and effective approach to determining hardiness (Colombo and others 1995; Bigras 1997).

Electrolytes are ions which are located within the cell membrane. Unstressed, undamaged plant cells will maintain these electrolytes within the membrane. As the cells are subjected to physical or environmental stresses, their membranes lose integrity. Damaged membranes allow electrolytes from injured cells to flow into the xylem. An estimation of damage can be made by comparing the conductivity of the leaked contents from injured and uninjured tissues in solution (Mattsson 1996).

For conifers, needles are the most commonly sampled tissues for EL (Burr 1990). Sampling of leaves is particularly applicable to evergreens, which can be sampled and tested throughout the dormant period. Roots (McKay 1992) and stem tissues (Colombo and others 1995) have also been used. The efficacy of EL in predicting cold hardiness has resulted in its use in operational practice at some nurseries, particularly for determining lifting windows and storability (Tinus 1996). For hardwoods, there is relatively little information available. Most EL research in the past was performed using roots of European species (Edwards 1998; McKay and others 1999; O'Reilly and others 2001). Important hardwood species of eastern North America have not been well represented. Therefore, the objectives of this study were: 1) to evaluate EL from stem tissues as a method for estimating hardiness and growth potential in eastern hardwoods; and 2) to observe changes in dormancy status that occur in response to different methods and duration of post-lifting storage.

Materials and Methods

One-year-old (1+0) bareroot seedlings of northern red oak (*Quercus rubra* L.), black walnut (*Juglans nigra* L.), and black cherry (*Prunus serotina* Ehrh.) of bulk seed origin were lifted from Vallonia Nursery, Vallonia, IN in November 2002 and divided among 2 storage treatments: cold storage (3 °C [37 °F]) and freezer storage (–2 °C [28 °F]). A third treatment consisted of seedlings remaining in the nursery to receive ambient environmental conditions during the storage period. Cold and freezer stored seedlings were bundled in kraft paper rolls with moistened peat moss, similar to those in Figure 1. Cold storage was in a thermostatically controlled cooler and freezer storage was in a Conviron PGR-15 (Controlled Environments Ltd, Winnipeg, MB) growth chamber. At monthly intervals from January until April, 21 trees of each species were removed from each of the storage regimes.

With the exception of ambient trees in January (frozen soil), 5 trees of each species/storage combination were potted into 4-gal (15-l) Treepots™ containers (Stuewe and Sons, Inc, Corvallis, OR) using Scotts Metro-Mix 366-P (Scotts Co, Marysville, OH) and placed in a greenhouse after each removal from storage. Greenhouse environmental conditions were maintained at 23.9 °C (75 °F) day and 17.8 °C (64 °F) night, with a photoperiod determined by natural daylength. Water containing a complete fertilizer solution was applied as needed. The number of days to first budbreak (DBB) was recorded for each seedling as an indicator of the dormancy level. Measurements of height were recorded at potting and at 30, 60, and 90 days after potting (DAP). Height was measured from media level to the base of the terminal bud (Figure 2). Readings from 30, 60, and 90 DAP were expressed as percent increase from initial height measurements. These observed values provided an estimation of performance potential when the seedlings were subjected to the given treatment conditions.

Figure 1—Seedling packaging system using kraft paper bundles.

For the EL procedure, a 1-cm (0.4-in) long section of stem, cut at both ends, was removed from the top third of 16 seedlings from each species/storage combination. The 16 stem samples were individually placed into 20 ml (0.7 oz) copolymer polypropylene vials (RPI Corp, Mt Prospect, IL) containing 15 ml (0.5 oz) of deionized water. Four samples

Figure 2—Measuring the height of black cherry.

were randomly assigned to 1 of 4 freeze test temperatures—3 (control), –10, –20, –40 °C (37, 14, –4, –40 °F). Sample vials were capped and the control treatment placed into a refrigerator where it was not exposed to freezing temperatures. The remaining treatments were placed into a Cryomed 1010 freezing unit (Thermo Forma, Marietta, OH) cooled by liquid nitrogen (Figure 3). Upon reaching each successive treatment, the respective vials were removed and placed in a refrigerator to thaw overnight. Sample vials of all treatments were then removed from refrigeration to complete thawing at room temperature. After thawing, stem EL values (total dissolved solids, ppm) were measured with a HI 9813 portable conductivity meter (Hanna Instruments, Inc, Woonsocket, RI). After recording initial values, vials were placed in a Getinge/Castle autoclave (Getinge USA, Inc, Rochester, NY) for steam sterilization at 110 °C (230 °F) for 20 minutes to attain a level of complete EL. Conductivity for each sample was calculated as Percent EL = Initial EL/ Complete EL x 100. For the purpose of this paper, preliminary results from the –20 °C freeze test will be discussed.

Results and Discussion

Electrolyte Leakage

For samples frozen to –20 °C, there was a similar trend for all species when exposed to progressively longer storage durations. For northern red oak, EL from stem tissues was 20 to 25% after 2 months storage and rose steadily to the 40% range after 5 months. There were no clear differences between ambient, cooler, or freezer stored stock. EL from black cherry samples increased sharply from 20 to 30% after 2 months to around 75% at 5 months. Freezer stored black cherry seedlings exhibited the highest levels of leakage, particularly after 4 and 5 months of storage. Black walnut samples began at 15 to 30% and ended at 50 to 60%. Black walnut seedlings stored in the cooler had the lowest levels and those left in the nursery during winter and early spring had the highest levels.

The increase in EL with prolonged storage of seedlings seems to indicate that the chilling requirement was supplied in storage, resulting in a loss of dormancy and cold hardiness with continued exposure. Individual species showed different responses to the different storage regimes. The response of northern red oak did not differ among storage regimes. This might be attributed to a greater chilling requirement or higher level of dormancy, as evidenced by the lower EL levels compared to the other species. The high EL of freezer stored black cherry seedlings may be a result of a low chilling requirement and an increased sensitivity to freezing temperatures in a storage environment. High EL levels in black walnut seedlings receiving ambient conditions could indicate that cold and freezer storage regimes are effective in maintaining a lower degree of physiological activity for this species.

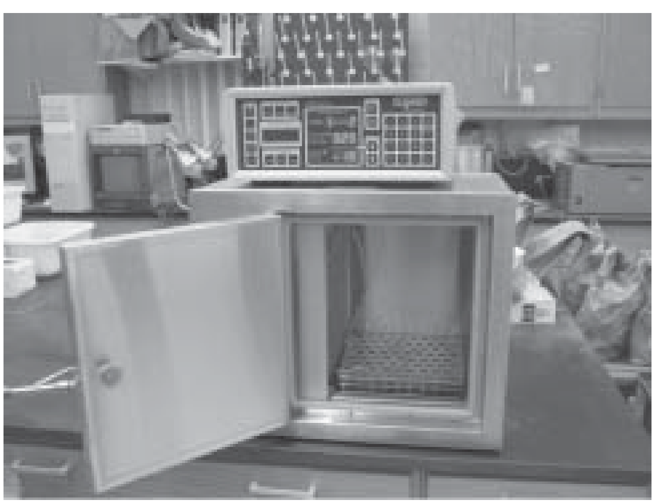

Figure 3—Cryomed freezing chamber.

Dormancy Status

Days to first budbreak was used as an indicator of seedling dormancy status. The number of DBB followed a trend that was opposite to that of EL. While EL increased with longer storage duration, DBB decreased over the same period. Northern red oak required more DBB than the other species. DBB decreased from around 45 days after 2 months storage to between 0 and 20 days after 5 months. Seedlings that were in the nursery had already leafed out after the 5-month period, while freezer-stored trees required about 20 days. Black cherry seedlings needed the fewest days for budbreak. After 2 months, DBB was 15 to 20 days. This decreased to 0 to 10 days after 5 months. Black walnut seedlings followed the same trend, with DBB decreasing from 25 to 30 days to 0 to 20 days. As was the case with the oaks, ambient cherry and walnut had broken bud before the end of the 5-month storage duration. Freezer stored seedlings also required the most DBB.

DBB decreased with longer storage durations, while stem EL levels increased. Fewer DBB and high EL levels both point to an increase in physiological activity and loss of hardiness. While a relationship between EL and DBB might be indicated by the given results, there were some unexpected outcomes. For example, freezer-stored seedlings of all species tended to have the highest EL values, but required the most DBB as well. Reasons for this are unclear. This may be associated with high levels of shoot desiccation in the freezer. Packaging materials did not completely enclose the seedlings, thereby exposing much of the stem tissue to freezing conditions. Consequently, there was a higher occurrence of terminal bud mortality compared to cold stored and ambient seedlings, particularly in black cherry and black walnut. This mortality may have altered seedling budbreak patterns.

Seedling Height

Height measurements did not appear to be consistently associated with EL, but rather depended on storage conditions. Cooler stored northern red oak showed a height increase of 50 to 100% in the greenhouse following a 2- to 4-month storage period, while freezer and ambient seedlings had increases of 20 to 30%. For black cherry, cooler stored seedlings increased in height from 100 to 200%. Freezer and ambient seedlings decreased (225 to 175% and 150 to 75%, respectively) during the period. Ambient and cooler stored black walnut seedlings increased in height (25 to 55%) while those stored in the freezer decreased (15 to 5%).

Declines in height growth for freezer stored black cherry and black walnut seedlings might be attributed to high levels of terminal bud mortality. Cooler stored seedlings of all species exhibited the highest increases in height as storage duration was extended. Otherwise, it is difficult to discern trends in height growth that may be related to EL and hardiness level.

Future Directions

Future research into EL can be extended to include a number of different plant tissues, such as roots and buds. Other characteristics, such as lateral versus terminal buds or fine versus coarse roots, could also be useful. The method of packaging seedlings for storage should also be considered, particularly when dealing with subfreezing conditions. In addition, because the seedlings for this project were germinated from seeds collected over a relatively large geographic range in Indiana, it is likely that genetic differences are responsible for some variation. Therefore, it may be helpful to reduce this variation by using half-sib plant material. Rapid methods for measuring cold hardiness and dormancy status will benefit nursery managers by allowing prompt assessment of seedling storability and performance potential. This study will provide useful information for planning and implementing related projects in the future.

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Slow Release Fertilization Reduces Nitrate Leaching in Bareroot Production of *Pinus strobus* Seedlings

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Abstract: The nitrate (NO_3^-) leaching potential from bareroot tree nurseries is great, yet no researchers have investigated the effect of slow release fertilization on NO_3^- leachate concentrations. The effects of slow release fertilizer on nitrate-nitrogen (NO_3–N) leachate concentrations, seedling morphology and nutrient content, soil nitrogen (N), and cation leachate concentrations were studied in the bareroot production of *Pinus strobus* (L.) (eastern white pine) seedlings in southwestern Wisconsin. Three fertilizer treatments were used: slow release 1 (SRF1, 19N:6P_2O_5:1K_2O); slow release 2 (SRF2, 12N:0P_2O_5:42K_2O); and a conventional fertilizer (Conv, 15.5N:0P_2O_5:0K_2O). A total of 180 and 52 kg N/ha (161 and 47 lb/ac) were applied in the Conv and SRF treatments, respectively. Over a 2-year period, soil leachate concentrations were collected weekly (May to December) from porous cup samplers installed at a depth of 1 m (3.3 ft) below the surface; soil was collected every 2 weeks, and plant tissue was collected once at the end of each growing season (late August). There were no differences in seedling morphology (height, diameter, dry mass) during the first or second growing season. Seedling nutrient concentrations were the same for all treatments at the end of first growing season, but Conv-treated seedlings contained greater concentrations of N (33 g/kg N for Conv compared to 30 g/kg for SRF) by the end of the second growing season. Nitrate-N leachate concentrations were greater for the Conv treatment compared to both SRF treatments during the first and second growing seasons. However, treatment did not affect cation leachate concentrations. Similarly, there was little difference in soil N among treatments. Overall, SRF reduced NO_3–N leachate concentrations in bareroot nursery tree production without sacrificing seedling quality.

Keywords: ground water contamination, nutrient uptake, environmental quality

Introduction

Concern over nonpoint ground-water contamination has directed much attention and research into reducing ground-water pollution by nitrogen-based fertilizers in agricultural systems. In bareroot nurseries, multiple applications of fertilizer nitrogen (N) have been applied throughout the growing season in an attempt to raise soil N (van den Driessche 1988). However, soil N is often in excess of plant N uptake, which results in the leaching of nitrate (NO_3^-) from the root zone (Weed and Kanwar 1996; Bundy and Malone 1998). Once leached from the root zone, NO_3^- can enter the ground water and, in large concentrations, is a public health concern (Goodrich and others 1991).

Few researchers have investigated NO_3^- leaching potential from bareroot tree nurseries relative to agricultural systems where N cycling is well documented (Tyler and Thomas 1977; Lowery and others 1998; Brye and others 2001). Nitrate-N leachate concentrations of 35 mg/L and 15 to 20 mg/L were measured at 15-cm and 1-m (6-in and 3.3-ft) depths, respectively, in an investigation of 6 bareroot nurseries in the midwestern US (Schultz and others 1993). Similarly, a study performed by the US Department of Agriculture (USDA) Forest Service found NO_3–N concentrations in 11 Forest Service nurseries as high as 55 mg/L, but NO_3–N concentrations consistently occurring between 1 to 11 mg/L (Landis and others 1992).

Most bareroot tree nurseries are located on loamy sands for increased ease of planting, pruning, harvesting, and management of soil fertility parameters. Because these soils are highly susceptible to leaching of NO_3^-, calcium (Ca^{2+}), potassium (K^+), and magnesium (Mg^{2+}) (Fisher and Binkley 2000), bareroot tree nurseries rely on conventional, soluble N-based fertilizers, applied several times throughout the growing season to maintain a steady supply of N. As a result, rates of conventional N-based fertilizer application in bareroot tree nurseries often exceed rates applied in other agricultural systems (Shultz and others 1993).

Application of slow release fertilizer (SRF), also commonly referred to as controlled release fertilizer (CRF), in bareroot tree nurseries has remained limited despite research suggesting comparable growth results from compounds such as isobutylidene diurea (Benzian and others 1969, 1971) and Osmocote® (van den Driessche 1988) on slow-growing conifer species. Moreover, the use of SRF has been shown to reduce NO_3–N leaching in containerized nursery systems (Rathier and Frink 1989; Yeager and others 1993). Low use rates may be blamed on lack of nursery formulations and availability of SRFs. However, new polymer-based technology has allowed for more SRF fertilizer formulations suitable for bareroot tree nursery production. In addition, SRFs are available in a variety of nutrient release periods (for example, 3-month, 6-month, 12-month) allowing nursery managers to tailor SRFs to target nutrient demand.

The objective of this study was to compare the effects of conventional and slow release fertilization of *Pinus strobus* (L.) (eastern white pine) seedlings within a bareroot tree nursery on: 1) NO_3–N leachate concentrations; 2) soil N levels; 3) seedling quality (that is, morphology and nutrient content); and 4) cation concentrations in soil and leachate. We hypothesized that the nutrient release rate characteristic of SRF would more closely parallel seedling N demand, thereby reducing N loss from the rooting zone without sacrificing seedling quality. To our knowledge, this report is the first to evaluate NO_3–N leaching under conventional fertilizer and SRF treatments in bareroot tree production.

Materials and Methods

Site Description

The study was conducted in southwestern Wisconsin in the Lower Wisconsin River Valley (LWRV) at the FG Wilson State Tree Nursery, Boscobel, WI (43° 14'N, 90° 70'W) operated by the Wisconsin Department of Natural Resources (WDNR). The soil is classified as Sparta loamy fine sand (*Entic Hapludolls*) with very dark gray loamy fine to medium sand at the surface that grades to yellowish-brown fine to medium sand at depths between 46 and 61 cm (18 and 24 in) (Soil Conservation Service 1951). Runoff was not considered as a potential source of N loss because of the level topography and high infiltration rate characteristic of the alluvial sand plain within the LWRV (Hart and others 1994). Following cultural practices at the nursery, organic matter additions, primarily peat, are supplied as needed to maintain the organic matter content close to 20 g/kg (0.3 oz/lb). Seedbeds are left fallow (sorghum-sudan grass and winter wheat are planted as cover crops to minimize wind erosion) for 2 y following seedling harvest and fumigated with methyl bromide prior to seeding.

Experimental Design

In the fall of 1998, *P. strobus* seeds were sown mechanically into seedbeds at a density of 377 seedlings/m^2 (35 seedlings/ft^2). Two Polyon® (Pursell Technologies, Inc., Sylacauga, AL 35150) polymer-coated slow release fertilizer (SRF) treatments, slow release fertilizer treatment 1, SRF1 (19N:6P_2O_5:12K_2O, comprised of 9.0% NO_3–N, 10.0% NH_4–N) and slow release fertilizer treatment 2, SRF2 (12N:0P_2O_5:42K_2O, comprised of 12.0% NO_3–N) both with a 5- to 6-month release at 27 °C [81 °F]), and a conventional water-soluble fertilizer, Conv (15.5N:0P_2O_5:0K_2O, comprised of 15.5% $CaNO_3$–N) were randomly applied to 6 of the 8 rows within a designated seedbed (rows adjacent to irrigation lines were not used), so that each treatment was applied to 2 rows (Figure 1).

All fertilizer treatments were topdressed using a tractor-propelled Gandy spreader. During the first (1999) and second (2000) growing seasons, both SRFs were applied at 24 kg N/ha (21.5 lb N/ac) per application, and Conv fertilizer was applied at 18 kg N/ha (16 lb N/ac) per application over intervals typical of the nursery conventional fertilization regime (Table 1). Following nursery protocol, 2 applications

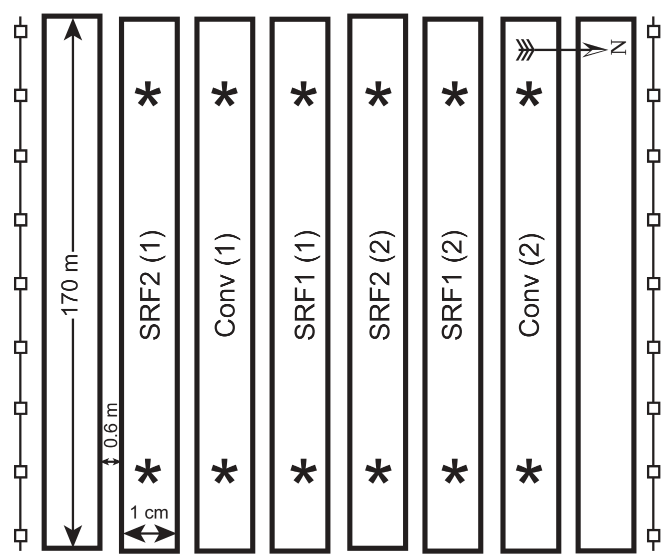

Figure 1—Schematic showing seedbed dimensions, fertilizer treatments (number in parentheses after treatment represents row number used in statistical analysis), and location of porous cup samplers (star).

Table 1—Summary of N application (kg N/ha), and application date over 2 years for conventional (Conv), slow release 1 (SRF1), and slow release 2 (SRF2) fertilizer treatments.

Treatment	Nitrogen application	Application date
	kg/ha	*Julian day*
1999		
Conv[a]	18	144, 154, 161, 169, 180, 187, 193, 204, 223, 232
SRF1[b]	24	146, 180[d]
SRF2[c]	24	146, 180[d]
2000		
Conv	18	130, 138, 145, 151, 158, 168, 174, 182, 203, 210
SRF1	24	132[d], 171
SRF2	24	132[d], 171

[a]Water soluble fertilizer 15.5N:0P_2O_5:0K_2O and 18N:46P_2O_5:0K_2O on Julian day 187, 232.
[b]Slow release fertilizer 19N:6P_2O_5:12K_2O.
[c]Slow release fertilizer 12N:0P_2O_5:42K_2O.
[d]Plus 15% water soluble 21N:7P_2O_5:14K_2O .

of Epsom salts ($MgSO_4$) at 134 kg/ha (119 lb/ac) and 3 applications of potassium sulfate (K_2SO_4) at 90 kg/ha (80 lb/ac) were applied to all treatments. Shortly after the first application of slow release fertilizer on May 26, 1999 (Julian day 146), heavy rainfall dislodged and transported a significant quantity of the slow release capsules into the shallow tractor furrows between rows. To compensate for the displaced fertilizer, both SRFs were reapplied, along with 15% water-soluble fertilizer to act as a N boost, and manually incorporated into the top 1 in (2.5 cm) of the soil. Because our study was conducted within the production area of the nursery, cultural practices such as pest control, weeding, and irrigation followed routine nursery operations in all treatments.

Leachate Sampling and Analysis

Leachate samples were collected using ceramic porous-cup samplers (PCS) (Timco Mfg Co, Prairie du Sac, WI 53578) fitted with high-density polyethethlyene tubing (0.43 cm [0.17 in] inside diameter) attached to both sample and vacuum lines of the sampler. Prior to installation, each porous-cup sampler was rinsed 3 times with deionized water and tested for leaks under a positive pressure of 100 kPa (1 bar) according to the manufacturers reported air-entry value (McGuire and others 1992). The samplers were installed on May 19, 1999 (Julian day 139), at 1 m (3 ft) below the surface following procedures described by Hart and Lowery (1997). Samplers were positioned as illustrated in Figure 1. A hand pump was used to apply a 65 kPa (0.65 bar) falling head, negative pressure to all PCS after each sampling. The first sample, collected on May 26 (Julian day 146), was discarded to minimize contamination. Beginning on June 2 (Julian day 151), samples were collected weekly through September and every other week through mid-December. Samples were transported back to the laboratory in an ice-filled cooler and stored at 4 °C (39 °F) until analysis.

To determine leachate ion concentrations, a 0.2 µm filter luer-locked to a 3 ml syringe was used to subsample the leachate samples into an amber vial with a penetrable Teflon-lined rubber cap. Nitrate-N concentrations were determined using a Dionex DX500 ion chromatogram (Dionex corporation, Sunnyvale, CA 94088). Total minerals were determined by inductively coupled plasma analysis (ICP) using a Quantometer 34000 (Thermo Jarrell Ash Corporation, Franklin, MA 02038). We followed the same sample preparation and analysis protocol for all water samples collected from irrigation inlets.

Rainfall and irrigation data were collected using a tipping bucket rain gauge attached to a cylindrical drum recorder. In addition, 3 manual, wedge-shaped rain gauges, spaced 1.5 m (5 ft) apart, were installed adjacent to the tipping bucket to record irregular spatial distribution within the irrigation system. Local temperature data were interpolated from nearby automated weather observation stations.

Soil Sampling and Analysis

Soil samples were collected every other week beginning May 19, 1999 (Julian day 139), using a 1.9-cm (0.75-in) diameter manual soil probe from 0 to 15 cm (0 to 6 in). Two composite soil samples comprised of 6 to 8 cores were collected within each treatment row, one at each end. Soil samples were immediately subsampled for determination of total N, NH_4–N, and NO_3–N. Kjeldahl total N, along with 2 *M* KCl extractable NH_4–N and NO_3–N were analyzed according to the Wisconsin Procedures for Soil Testing and Plant Analysis (1987) using flow injection analysis (FIA). The remaining portions of the soil sample were dried in a forced air dryer at 60 °C (140 °F) then passed through an 841-µm sieve. Forest soil analyses performed included pH (electrometric), percent silt and clay (Cenco-Wilde), organic matter content (potassium dichromate in H_2SO_4 by oxidation and titration), available P (0.002 *N* H_2SO_4 Murphy-Riley), and 1 *M* NH_4OAc-extractable potassium (K^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}) according to Wilde and others (1979).

Seedling Collection and Analysis

At the end of each growing season (late August), 40 to 80 seedlings were randomly sampled from each treatment row and measured for height (root collar to terminal bud) and diameter (immediately above the root collar). Seedlings were rinsed with deionized water and dried in a forced air dryer at 60 °C (140 °F) for 3 days. After dry weights were measured, plant tissues were ground and wet-ashed using a 6:1 ratio of HNO_3:$HClO_4$ acids and analyzed for P, K, Ca, and Mg by ICP analysis. Kjeldahl tissue nitrogen was analyzed according to the Wisconsin Procedures for Soil Testing and Plant Analysis (1987) by FIA.

Nitrogen Loading Analysis

Nitrogen loading to the ground water was calculated by:

$$\mathbf{J_w = D_w C}$$

where J_w (mass/volume^2/time) is the loading or solute flux, C (mass/volume^3) is NO_3–N concentration, and the drainage rate (D_w) (volume/time) was calculated using the following equation:

$$D_w = (P+I) - (ET+RO) \pm \Delta S$$

The P = precipitation (volume/time) and I = irrigation rate (volume/time), which was measured on site. ET = potential evapotranspiration rate (volume/time) interpolated from nearby automated weather observation stations, RO = runoff (volume/time, assumed to be zero for Sparta sand), and ΔS = change in water storage over time (volume/time, also assumed to be zero for the Sparta sand over a long period of time) (Hart and others 1994; Lowery and others 1998).

Statistical Analyses

The MIXED procedure in SAS (SAS 1998) was used to fit 3 different models comparing the main effect of fertilizer treatment (Conv, SRF1, SRF2) on each of 3 response variables:

- *Full* model: **Y = m + type + row(type) + e,** where **Y** = response variable; **m** = overall mean; **type =** effect of fertilizer treatment; **row(type)** = random effect of row number (1 or 2) nested within type; **e** = residual error term;
- *Reduced* model: **Y = m + type + e**;
- *Point* model: **Y = m + type + point + type*point + e,** where **point =** random effect of sample position (east or west); **type*point** = interaction between effect of fertilizer treatment and sample position.

A likelihood test was used to evaluate the significance of row number as a random effect between models 1 and 2, and model 3 was performed to check if sample position was random. Pearson linear correlations were computed using the CORR procedure in SAS.

Results

Leachate

Nitrate-N concentrations in irrigation water ranged from 5.62 to 9.32 mg/L, and pH fluctuated between 7.10 and 8.08 throughout the study. Concentrations of K^+, Ca^{2+}, and Mg^{2+} in irrigation water ranged from undetectable to 8.86 mg/L, 21.3 to 40.0 mg/L, and 10.0 to 19.31 mg/L, respectively.

During the first growing season (1999) mean NO_3–N leachate concentrations were greater ($P < 0.05$) in the Conv treatment compared to both SRF treatments (Figure 2). There were no significant differences between SRF treatments. In the Conv treatment, NO_3–N concentrations peaked in late July at 66 mg/L and remained above 50 mg/L until December (Figure 2). Two similar peaks in NO_3–N concentrations were evident in each SRF treatment, the first in early August (SRF1 at 35 mg/L; SRF2 at 44 mg/L) and the second in early October (SRF1 at 43 mg/L; SRF2 at 48 mg/L). Thereafter, NO_3–N concentrations steadily declined to approximately 18 and 26 mg/L in SRF1 and SRF2, respectively (Figure 2).

During the second growing season (2000), peak NO_3–N leachate concentrations for all treatments were considerably less than the peak concentrations recorded in 1999. As in the first growing season, NO_3–N concentrations for the Conv treatment were greater ($P < 0.05$) than each of the SRF treatments (Figure 3). Likewise, no significant differences were observed between SRF treatments. In the Conv treatment, there were 2 separate NO_3N peaks; the first peak occurred in early June (20 mg/L) and the second in late August (16 mg/L) (Figure 3). The maximum NO_3–N leachate concentrations observed for the SRF1 and SRF2 treatment were 3 and 8 mg/L, respectively. In the later portion (Julian days 310 to d 330) of the second growing season, NO_3–N leachate concentrations in the Conv treatment declined to levels observed in both SRF treatment groups (~ 4 to 5 mg/L) (Figure 3).

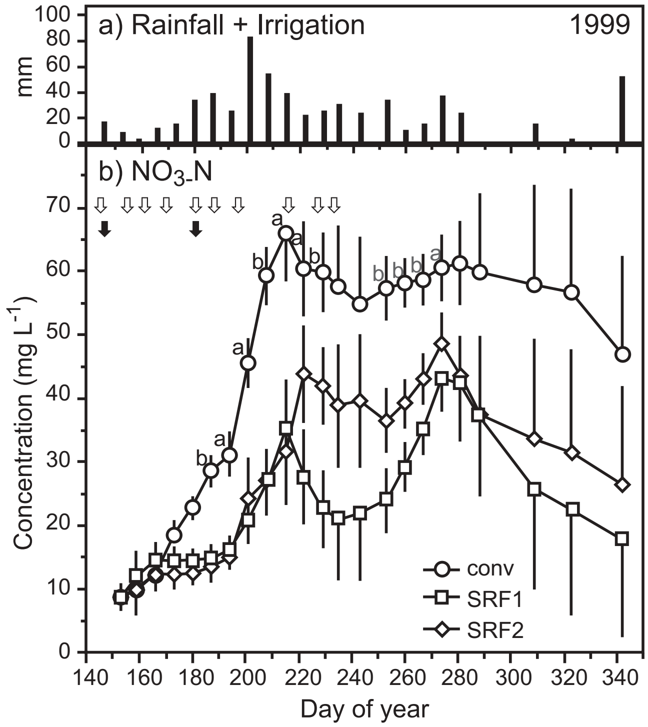

Figure 2—a) Rainfall and irrigation summed between sampling dates from May 1999 to December 1999. b) Average NO_3–N soil water leachate concentrations at 1-m (3-ft) depth for 1999. Filled and open arrows represent slow release and conventional fertilizer applications, respectively.

There were no treatment differences ($P < 0.05$) in leachate cation (K^+, Ca^{2+}, Mg^{2+}) concentrations during the 1999 or 2000 growing season (Figures 4 and 5). In all treatments, K^+ leachate concentrations were undetectable at the onset of the first growing season and then abruptly increased during late July. Following this abrupt increase, K^+ concentrations gradually decreased for the remainder of the first and throughout the second growing season. Calcium leachate concentrations for all treatments were greatest during the first growing season and remained relatively constant during both sampling periods (Figures 4 and 5). Contrary to Ca^{2+}, Mg^{2+} leachate concentrations for each treatment were greater during the second growing season and displayed the greatest variability among and within treatments (Figures 4 and 5). Although not significantly

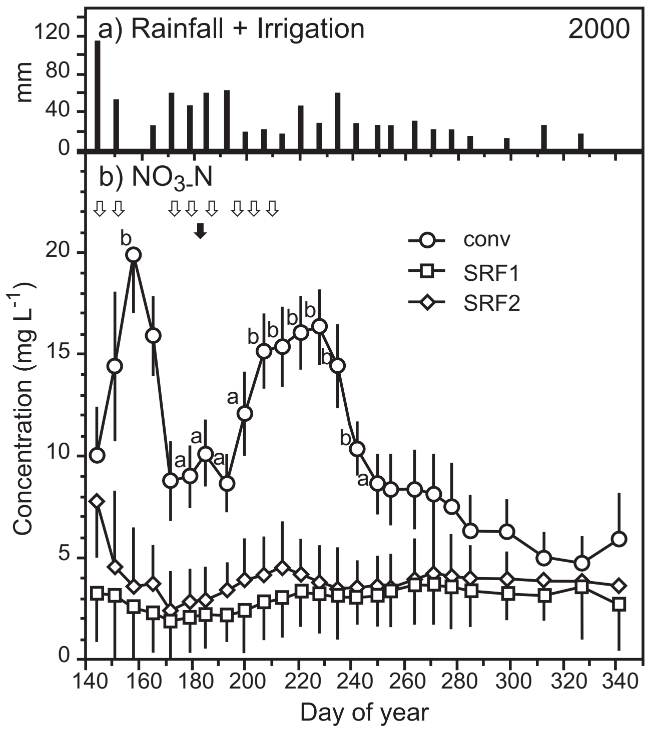

Figure 3—a) Rainfall and irrigation summed between sampling dates from May 2000 to December 2000. b) Average NO_3N soil water leachate concentrations at 1-m (3-ft) depth for 20a)00. Filled and open arrows represent slow release and conventional fertilizer applications, respectively.

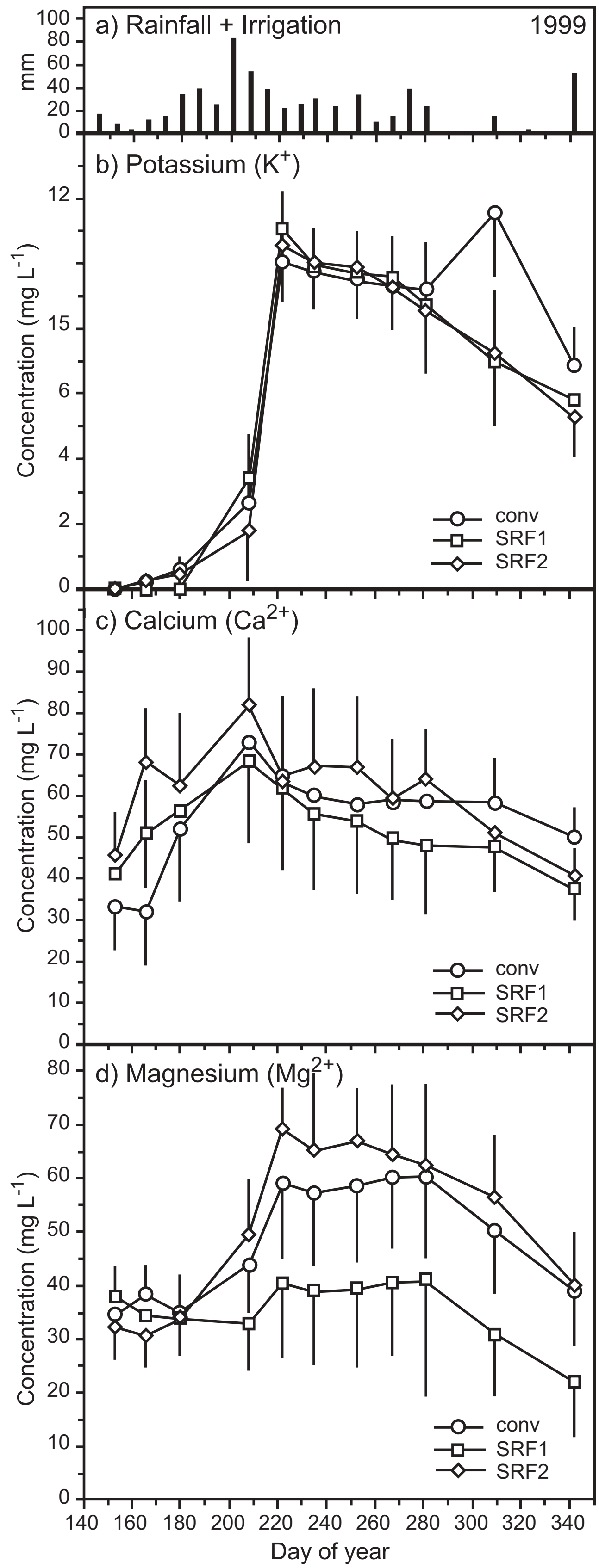

Figure 4—a) Rainfall and irrigation summed between sampling dates from May 1999 to December 1999. Average cation b) potassium, c) calcium, and d) magnesium soil water leachate concentrations for 1999.

greater, Mg^{2+} concentrations in the leachate of the SRF2 treatment were consistently greater than those observed in both Conv and SRF1 treatments during both the first and second growing seasons.

Leachate Correlations

During the first growing season, K^+ leachate concentrations were highly ($P < 0.01$) correlated (SRF1 $r = 0.62$; SRF2 $r = 0.70$; Conv $r = 0.72$) with NO_3–N leachate concentrations. The relationship between concentrations of NO_3–N and Ca^{2+} (SRF1 $r = –0.04$ [$P > 0.01$]; SRF2 $r = –0.02$ [$P > 0.01$]; Conv $r = 0.45$ [$P < 0.01$]) or Mg^{2+} (SRF1 $r = 0.16$ [$P > 0.01$]; SRF2 $r = 0.70$ [$P < 0.01$]; Conv $r = 0.37$ [$P < 0.01$]) was mixed. Nitrate-N leachate concentrations were weakly correlated to cation leachate concentrations during the second growing season, except for SRF2 NO_3–N and Mg^{2+} ($r = 0.55$ [$P < 0.01$]) and Conv NO_3–N and K^+ ($r = 0.47$ [$P < 0.01$]).

Nitrogen Loading

There was significantly greater N leached from Conv compared with SRF treatments in 1999 and 2000 (Table 2). Nitrogen loading to the ground water accounted for approximately half of the difference between N applied and plant N uptake in the Conv treatment during both 1999 and 2000.

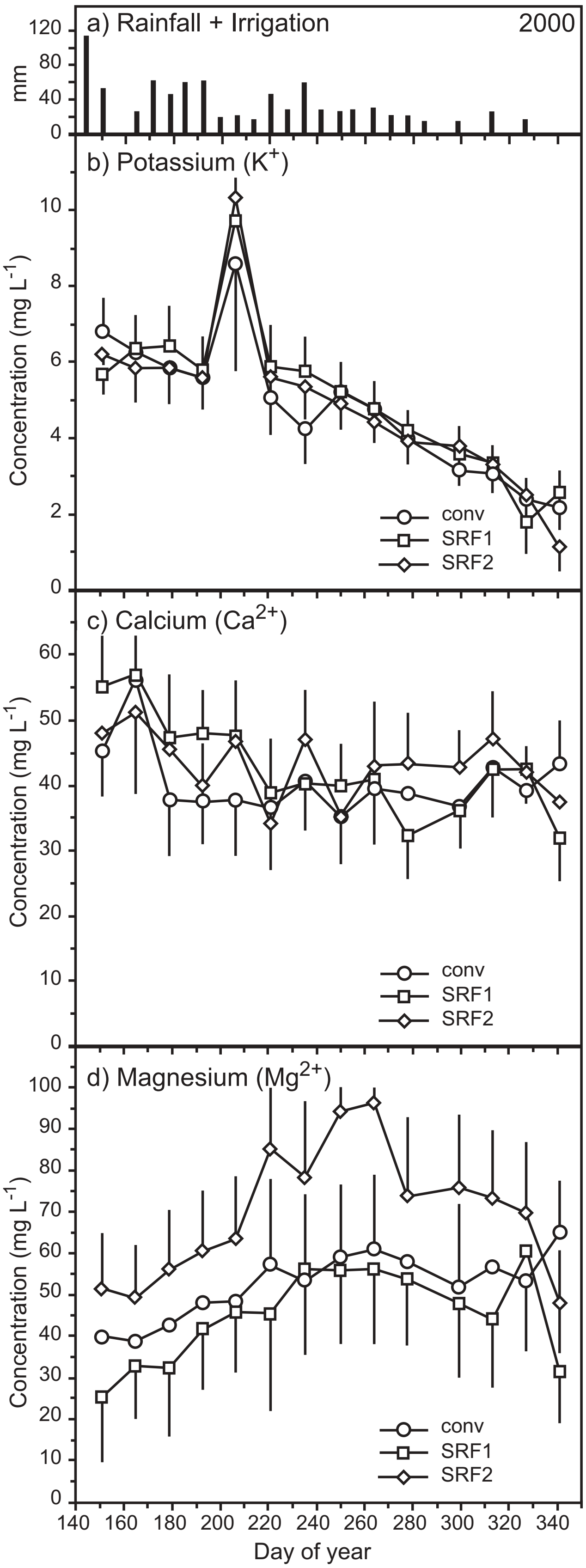

Figure 5—a) Rainfall and irrigation summed between sampling dates from May 2000 to December 2000. Average cation b) potassium, c) calcium, and d) magnesium soil water leachate concentrations for 2000.

Table 2—Nitrogen applied plant N uptake and estimated N leached for conventional (Conv), slow release 1 (SRF1), and slow release 2 (SRF2) fertilizer treatments over 2 growing seasons.

	N applied[a]	N uptake[b]	Estimated N leached[c,d]
	- - - - - - - - - -	*kg/ha*	- - - - - - - - - -
1999			
Conv	180	19	73 a
SRF1	52	19	34 b
SRF2	52	19	40 b
2000			
Conv	180	80	52 a
SRF1	52	61	11 b
SRF2	52	62	15 b

[a]Total from May through August.
[b]Total from May through August.
[c]Total from May through December.
[d]Estimated N leached with the same letter are not significant at $P > 0.01$ within a year.

Nitrate-N loading for SRF treatments were greater than the difference between N applied and plant N uptake in both the first (–1 kg/ha [–0.9 lb/ac] SRF1; –10 kg/ha [–8.9 lb/ac] SRF2) and second (–20 kg/ha [–17.9 lb/ac] SRF1; –25 kg/ha [–22.3 lb/ac] SRF2) growing season (Table 2).

Soil

Before fertilizer application, soil pH, percent organic matter, available P, K^+, Ca^{2+}, and Mg^{2+} were similar ($P < 0.05$) among treatment plots (Table 3). At the end of the second growing season, soil pH in all 3 treatment groups increased (Table 3). As expected, soil organic matter decreased in all treatments after 2 growing seasons, but there were no differences among treatments (Table 3). Available phosphorus increased from the first to the second y in Conv, but remained the same in both SRF treatments. Potassium levels were greater ($P < 0.01$) after 2 years in the Conv treatment compared to SRF1 and SRF2 treatments. Calcium levels declined after 2 growing seasons in both SRF treatments; however, Ca increased in the Conv treatment, though not significantly ($P < 0.05$), with the addition of Ca applied as $CaNO_3$ in 15.5N:0P_2O_5:0K_2O (Table 3).

There were no differences ($P > 0.05$) in total soil N during the first or second growing season for all treatments (Table 4). In all treatments, average total soil N in the first growing season was greater in June than any other month of the year. During the second growing season, total N values were greatest during August for all 3 treatments. Soil NO_3^- values during the first season were numerically greater in the Conv treatment from May through August; however, the only significant ($P < 0.01$) difference between Conv and both SRFs was detected in June (Table 4). Though not significant, soil NO_3^- concentrations in the Conv treatment was numerically greater than soil NO_3^- concentrations in the SRF treatments during the early (May, June, and July) portion of the second season. Similar to total N, there were no differences ($P > 0.05$) in soil NH_4^+ concentrations observed during the first or second growing season. For all treatments, soil NH_4^+ concentrations were greatest in June

Table 3—Soil fertility characteristics sampled prior to project initiation (1999 May) and at end of second growing season (2000 September) for conventional (Conv), slow release 1 (SRF1), and slow release 2 (SRF2) fertilizer treatments.

Treatment	pH	Organic matter	P	K^{+} [a]	Ca^{2+}	Mg^{2+}
		percent	- - - - - *kg/ha* - - - - -		- - - - - *cmol/kg* - - - - -	
1999 May						
Conv	5.78	2.16	81	99	3.31	0.90
SRF1	5.82	2.33	91	113	3.52	.88
SRF2	5.77	2.24	84	113	3.48	.98
2000 September						
Conv	6.26	2.11	100	244 b†	3.56	1.04
SRF1	6.10	2.00	93	116 a	3.18	1.11
SRF2	6.18	2.05	91	164 a	2.97	1.07

[a]For K^{+}, data with the same letter are not significant at $P > 0.01$.

Table 4—Soil total N, NO_3^{-}, and NH_4^{+} averaged monthly from May through October during the first (1999) and second (2000) growing season for conventional (Conv), slow release 1 (SRF1), and slow release 2 (SRF2) fertilizer treatments.

Month	Treatment	Total N 1999	Total N 2000	NO_3^{-} 1999[a]	NO_3^{-} 2000	NH_4^{+} 1999	NH_4^{+} 2000
		- - - - - - - - -	- - - - - - - - -	- - - - *mg/L* - - - -	- - - - - - - -	- - - - - - - -	- - - - -
May							
	Conv	714	892	3.66	7.81	4.06	1.76
	SRF1	819	954	1.95	5.68	3.99	2.72
	SRF2	789	914	.86	3.03	4.19	2.20
June							
	Conv	1071	827	7.40 a	3.77	13.14	3.97
	SRF1	1052	866	2.60 b	.70	13.25	1.98
	SRF2	1027	851	3.28 b	1.12	12.18	1.59
July							
	Conv	962	835	7.44	1.98	7.80	5.33
	SRF1	998	886	5.45	1.42	6.93	4.26
	SRF2	945	884	7.31	1.23	7.32	5.30
August							
	Conv	957	1111	6.40	1.61	3.55	9.27
	SRF1	881	1038	4.55	2.18	3.84	10.08
	SRF2	913	1033	5.47	1.24	4.22	9.18
September[b]							
	Conv	—	1073	—	1.79	—	6.17
	SRF1	—	947	—	3.06	—	6.02
	SRF2	—	937	—	2.71	—	4.90
October							
	Conv	744	932	4.96	.75	6.09	2.14
	SRF1	727	882	5.46	.56	6.74	1.24
	SRF2	744	815	5.33	.51	6.57	2.50

[a]NO_3^{-} values for June 1999 with the same letter are not significant at $P > 0.01$.
[b]Data not available for 1999.

of the first growing season and August of the second growing season (Table 4).

Plant Tissue

There were no visual or qualitative differences in seedling appearance between treatments at the end of the first growing season (Figure 6). In late June to early August of the second growing season, the SRF-treated seedlings appeared slightly paler in color than the Conv-treated seedlings. However, by late August of the second growing season, there were no differences in seedling color between SRF and Conv-treated seedlings (Figure 7).

Dry mass, height, and diameter of *P. strobus* seedlings following the first growing season were similar ($P > 0.05$)

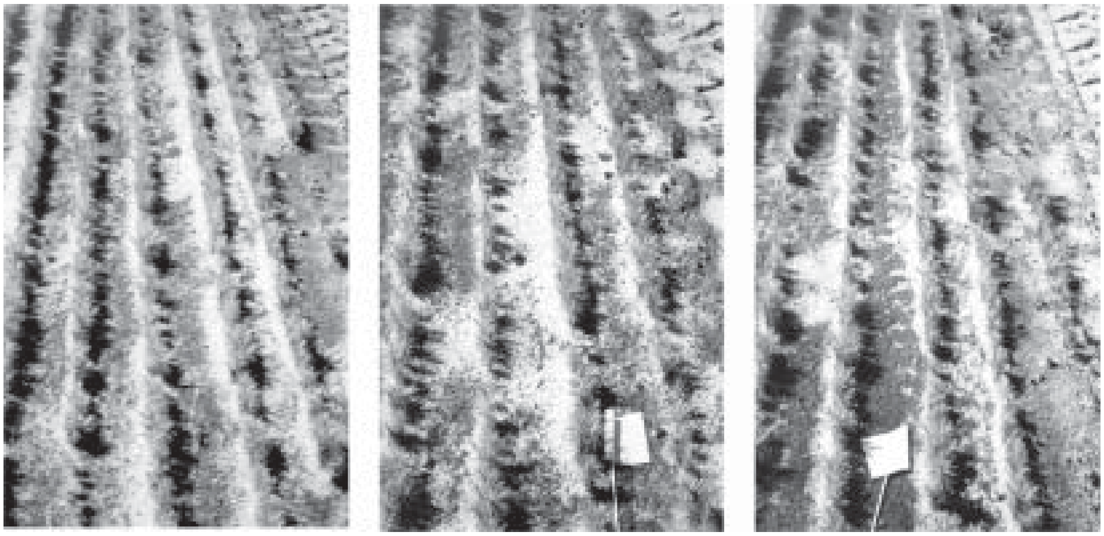

Figure 6—*Pinus strobus* (eastern white pine) seedlings after 1 growing season (late August 1999). From left to right, conventional (conv), slow release 1 (SRF1), and slow release 2 (SRF2) fertilizer treatments.

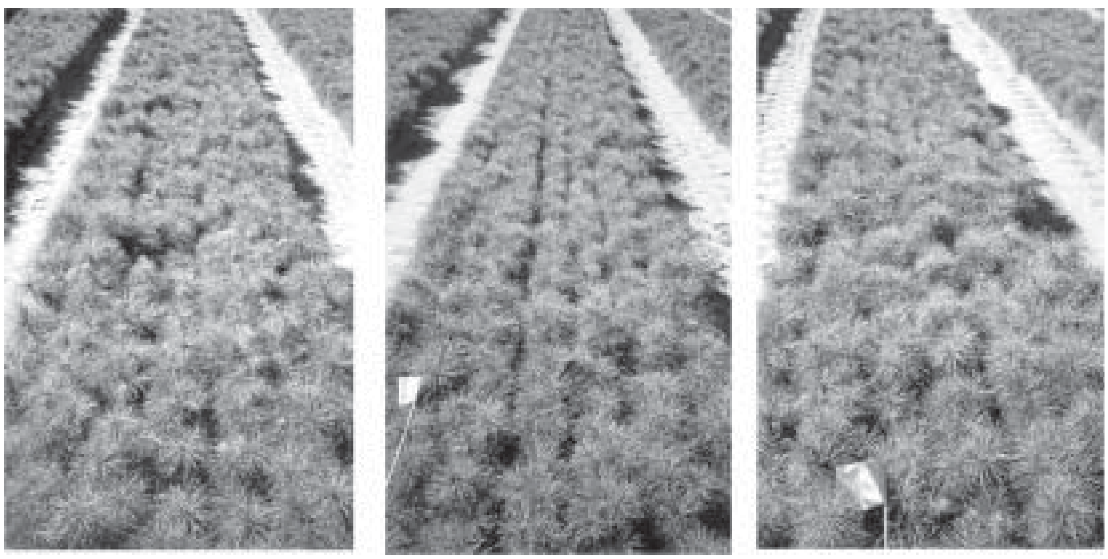

Figure 7—*Pinus strobus* (eastern white pine) seedlings after 2 growing seasons (late August 2000). From left to right, conventional (conv), slow release 1 (SRF1), and slow release 2 (SRF2) fertilizer treatments.

between treatments (Table 5). During the second growing season, the dry mass and heights were not different ($P > 0.05$); however, SRF2 seedling diameters were greater ($P < 0.05$) than both the Conv and SRF1 treatment seedlings. The diameter of the SRF2-treated seedlings increased an average of 92% from the first to the second season. In the Conv- and SRF1-treated seedlings, only a 6.2 and 16% mean increase in diameter was observed, respectively.

Plant uptake (g/kg) of total N and P did not differ between treatments during the first growing season (Table 6). The ratio of N uptake to N applied was ~10:1 for Conv compared to ~2.5:1 for both SRF1 and SRF2 (Table 2). Significantly lower ($P < 0.01$) concentrations of K^+ were observed in SRF1-treated seedlings compared to the Conv- and SRF2-treated seedlings. In addition, SRF2-treated seedlings displayed lower ($P < 0.05$) concentrations of Ca^{2+}, and SRF1-treated seedlings displayed lower concentrations of Mg^{2+} during the first growing season (Table 6).

Tissue analysis of seedlings sampled following the second growing season indicated that Conv-treated seedlings contained greater ($P < 0.05$) total N than either SRF1 or SRF2 treatments (Table 6). Nitrogen applied to N uptake ratios in each treatment group were: Conv (2.3:1), SRF1 (0.85:1), and SRF2 (0.84:1) (Table 2). Phosphorus, Ca^{2+}, and Mg^{2+} uptake

Table 5—Average morphological characteristics of *Pinus strobus* seedlings following the first and second growing season for conventional (Conv), slow release 1 (SRF1), and slow release 2 (SRF2) fertilizer treatments.

Treatment	Mass	Height[a]	Diameter[b]
	g/plant	*cm*	*mm*
1999			
Conv	0.29	6.11	2.59
SRF1	.28	6.10	2.33
SRF2	.30	6.05	1.56
2000			
Conv	2.01	19.3	2.75 b
SRF1	1.80	19.1	2.70 b
SRF2	1.84	18.6	3.00 a

[a]Root collar to tip of bud.
[b]Diameters for 2000 with the same letter are not significant at $P > 0.05$.

Table 6—Nutrient concentrations of *Pinus strobus* seedlings following the first and second growing season for conventional (Conv), slow release 1 (SRF1), and slow release 2 (SRF2) fertilizer treatments.

Treatment	Total Plant Uptake[a]				
	N[b]	P	K[c]	Ca[b]	Mg[b]
	- - - - - - - -	- - - - - - - -	*g/kg*	- - - - - - - -	- - - - - - - -
1999					
Conv	44	9.1	28 a	13 a	7.7 b
SRF1	47	9.4	23 b	12 a	8.6 a
SRF2	44	8.6	27 a	11 b	7.6 b
2000					
Conv	33 a	6.5	21 a	8.1	5.2
SRF1	30 b	6.5	6.0 c	8.7	6.2
SRF2	30 b	6.4	19 b	9.4	5.8

[a]Root plus aboveground biomass.
[b]Values for total N in 2000, Ca and Mg in 1999 with the same letter are not significant at $P > 0.05$.
[c]Values for K with the same letter are not significant $P < 0.01$.

did not differ; however, K^+ uptake was different ($P < 0.01$) between each treatment.

Discussion

To our knowledge, this report is the first to provide an evaluation of NO_3–N leaching after conventional and SRF fertilization in bareroot tree production. These data clearly indicate that the use of SRFs was associated with a dramatic reduction in N loss to the environment without relinquishing seedling quality.

During the first growing season, the NO_3–N leachate concentrations collected 1 m (3 ft) below the surface illustrated a large disparity between the amount of N applied compared to the amount of N sequestered by tree seedlings. This difference existed in each treatment group; the disparity was especially pronounced in the Conv treatment. Second season NO_3–N leachate concentrations decreased substantially in all 3 treatment groups; however, the Conv treatment again showed consistently greater N leachate concentrations than either SRF treatments. The dramatic differences in NO_3–N concentrations during the first and second growing seasons are most likely the result of differences in seedling N demand. Seedlings were planted in fall of 1998 and germinated in spring of 1999. Since equal amounts of N (kg/ha) were applied during the first and second growing season, the young seedlings in the first season were evidently being overwhelmed with N from the fertilizers. Since NO_3–N losses are minimized when N fertilizer additions parallel plant N demand (Iyer 1988; Weed and Kanwar 1996), one may expect that NO_3–N losses would be reduced if bareroot tree nursery N additions were more closely tied to seedling N demand.

During the second growing season, the amount (kg/ha) of N sequestered by the SRF-treated seedlings was greater than the amount of N applied as fertilizer (Table 6). This suggests that a portion of the SRF-treated seedling N uptake was derived from other nonfertilizer inputs such as N mineralization from organic matter and N deposition from precipitation. Iyer (1988) has previously estimated that N input from precipitation is 5 kg/ha/yr (4.5 lb/ac/yr) and that the rate N mineralization from organic matter inputs occurs at a rate of 2%/y. Using these values, it is estimated that approximately 65 kg N/ha/yr (58 lb N/ac/yr) was derived from nonfertilizer sources during this study. By accounting for both N mineralization and N deposition from precipitation, the negative N budget (N applied—[seedling N uptake + N leached]) (Table 6) observed in the SRF treatments during both years one and two would be reduced. In the Conv treatment, approximately half the difference between N applied and seedling N uptake is estimated to be leached during both the first and second growing seasons (Table 2). The discrepancy between the N budget for both SRF (negative differences) and the Conv (positive difference) treatments may be caused by the tendency of porous cup samplers to measure resident soil water concentrations rather than flux concentrations (Brandi Dohrn and others 1996), or the difference in data measurement time periods (seedling N uptake [May through August]; N leached [May through December]).

Since the nutrient release rate of SRFs (specifically Polyon® polymer-coated SRF) is positively correlated to increases in temperature (Lunt and Oerteli 1962; Cabrera 1997), warm temperatures may be responsible for NO_3–N leachate concentration peaks observed in both SRF treatments during September (maximum temperatures averaged 25 °C (77 °F) in early September) of the first growing season. Furthermore, Kochba and others (1990) determined that the rate of nutrient release by SRFs was linearly related to the water vapor pressure varying with temperature. Thus, it is plausible that warm temperatures provided conditions for increased nutrient release concurrent with decreased N demand by the conifer seedlings. The slight deviation observed between SRF1 and SRF2 during both the first and second growing season is likely due to the smaller percentage of NO_3–N found within the fertilizer composition of SRF1 (9% NO_3–N and 10% NH_4–N) compared with SRF2 (12% NO_3–N) (Figures 2 and 3).

Large rainfall events preceded peaks in NO_3–N leachate concentrations in all 3 treatment groups, but the peaks were especially prominent within the Conv treatment. The close relationship observed between leachate NO_3–N concentrations and rainfall events in the Conv treatment may explain why NO_3–N leachate concentrations during the first growing season remained above 50 mg/L until December, even though the last fertilizer application was made on Julian day 232 (late Aug) (Figure 1). Examination of rainfall data indicates that very little precipitation occurred during this time period. On the other hand, the NO_3–N leaching pattern characteristic of the SRF treatments may be more closely related to seedling N demand or the timing of fertilizer release.

Similar to the pattern in NO_3–N leachate concentrations, peak concentrations of K^+ and Mg^{2+} are closely associated with rainfall events. Despite increased levels of soil Ca^{2+} in the Conv treatment because of the addition of Ca as $Ca(NO_3)_2$, there were no observed increases in Ca^{2+} leachate concentrations. Increases in Mg^{2+} leachate concentrations across all 3 treatments during the second growing season are likely attributed to Epsom salt ($MgSO_4$) applications.

The positive relationship previously noted between nutrient release of SRFs and temperature may explain the patterns observed in soil NO_3^- concentrations during first and second growing seasons. Soil NO_3^- concentrations in the SRF treatments remained below Conv treatment soil NO_3^- concentrations in the spring, when temperatures were cool, and increased during the warmer summer months of July and August. Likewise, the SRF nutrient release pattern likely contributed to the slower decline in soil NO_3^- concentrations in the SRF treatment relative to the Conv treatment during the months of September 2000 and October 1999. In addition, increases in SRF soil NO_3^- concentrations during the latter part of the first growing season are similar to the second SRF leachate NO_3–N concentration peak observed during this time. In October of 2000, the low soil NO_3^- concentrations in all treatments were also consistent with the leachate NO_3–N concentrations.

During the first growing season, soil total N and NH_4^+ concentrations were greatest in the month of June, which is approximately 30 days following the first fertilization and prior to an appreciable increase in seedling N demand. Similarly, second growing season average monthly soil total N and NH_4^+ concentrations were greatest in the month of August, again consistent with an expected decline in seedling N demand. The lower average monthly concentrations of NH_4^+ and greater NO_3^- concentrations observed at the beginning of the second growing season can likely be attributed to the conversion of NH_4^+ to NO_3^- during spring months (Cabrera 1997; Havlin and others 1999). Despite the presence of NH_4–N in the SRF1 fertilizer formulation, soil NH_4^+ concentrations were not significantly different in the first or second growing season compared to Conv and SRF2 soil NH_4^+ concentrations.

Data on seedling N uptake, together with the NO_3–N leachate concentrations and ratios of N applied to N uptake during the first growing season, suggest that all 3 fertilizer treatments supplied adequate amounts of N to meet seedling N demand. However, an analysis of second season SRF1 and SRF2 treatment results show a decrease in seedling N uptake, exceptionally low NO_3–N leachate concentrations, and ratios of N applied to N uptake of 0.85:1 (SRF1) and 0.84:1 (SRF2). These results suggest one or both of the following: 1) the rate of SRF nutrient release did not match the rate of seedling N uptake; 2) the quantity of N applied (kg/ha) in both SRF treatments did not meet seedling N demand. Since the rate of nutrient release did not appear detrimental in first year growth, it is likely that an increase in the quantity of SRF N applied may correct this perceived N deficiency. However, since the tissue N concentrations for all treatments were within prescribed seedling N concentration ranges established by Iyer and others (1989) for conifer seedlings grown in bareroot nurseries, it is possible that the increase in N uptake by Conv seedlings reflects luxury consumption. Furthermore, efforts to maximize seedling performance in the nursery may be unnecessarily overemhasized if adequate seedling nutrient content is present at outplanting (van den Driessche 1988).

The practical use of SRFs in bareroot nursery tree production is often dismissed due to the high cost of the SRF (Donald 1973; McNabb and Heser 1997). On average, the commercial price of SRF is usually about 3 to 7 times greater per unit N than standard conventional fertilizer. However, in order to maintain soil N levels, more applications of conventional fertilizer are required. A simple economic analysis of fertilizer expenses at the FG Wilson State Tree Nursery revealed that, contrary to popular belief, the final cost of slow release fertilizer was actually less than that of the conventional fertilizer (Vande Hey 2000). Moreover, the economic benefits of SRFs extend well beyond the initial costs of the fertilizer. When the additional expenses of fuel, labor, and environmental impact (for example, soil compaction and ground-water pollution) are also accounted for, the economic benefits of slow release fertilizers become even greater.

Conclusions

The use of slow release fertilizers in bareroot nursery tree production significantly reduced NO_3–N leachate concentrations compared to conventional, water-soluble fertilizers. However, first year seedling growth and nutrient concentrations were not affected by fertilizer treatment. The seedling N concentration of the SRF-treated seedlings after the second growing season was less than that of the Conv-treated seedlings; however, morphological characteristics such as height and diameter did not differ. The slow release fertilization did not alter concentrations of K^+, Ca^{2+}, or Mg^{2+} compared with conventional fertilization. Soil total N and NH_4^+ concentrations were likewise not affected by fertilizer treatment; the initial differences observed in soil NO_3^- concentrations were likely caused by the nutrient release patterns characteristic of the SRF. Overall, there was little difference in NO_3–N leachate concentrations, seedling morphology, seedling nutrient concentrations, and soil total N, NO_3^-, and NH_4^+ concentrations between SRF1 and SRF2.

Results of this research indicate that SRF can provide both economical and environmental benefits without sacrificing seedling quality. Research is needed to develop SRF formulations and application rates in order to further increase SRF efficiency and reduce NO_3–N leaching in bareroot nursery tree production. As demand for responsible stewardship of the environment increases, traditional fertilization practices will require revision. Slow release fertilization appears to provide a promising alternative.

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Recent Trends in Hardwood Seedling Quality Assessment

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Abstract: The study and evaluation of hardwood seedling quality has been attracting more attention in recent years. This is in contrast to the many decades of extensive research on conifer seedling quality. As demand and production of hardwood seedlings increase, a need arises for efficient, replicable, and practical approaches to quality assessment. Many methods of determining conifer seedling quality may be transferred to hardwood production systems. However, the genetic, morphological, and physiological characteristics of hardwoods merit special consideration when applying these concepts. Current techniques for evaluating seedling quality are discussed.

Keywords: morphology, physiology, genetics, hardwood production, hardiness, dormancy

Introduction

Seedling quality is a term used to describe the extent to which a seedling may be expected to successfully survive and grow after outplanting (Duryea 1985; Mattsson 1996). While this is heavily dependent on factors such as species, nursery culture, storage, site conditions, and genetics, a quality seedling can be defined as one that will thrive once outplanted in the field. For many decades, measurement of morphological and physiological characteristics has been used as a tool to predict field performance of seedlings. Research into cultural treatments and procedures that result in optimal levels of these parameters has been of prime importance, as has the evaluation of different methods of assessment.

Because conifers dominate nursery production in all parts of the world, researchers have focused primarily on issues regarding their production and establishment. In the US alone, conifers represent 80 to 90% of total annual seedling production (1.7 billion trees) (Moulton and Hernandez 2000). Conifer species such as white pine (*Pinus strobus* L.), loblolly pine (*P. taeda* L.), red pine (*P. resinosa* Ait.), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), and white spruce (*Picea glauca* (Moench) Voss) have a long history of quality grading and nursery production research (Ziegler 1914; Wakeley 1948; Curtis 1955; Stone 1955; Slocum and Maki 1956; Dickson and others 1960). This review summarizes some of the more common methods of assessing seedling quality through morphological and physiological characteristics.

Increasing Importance of Hardwoods

As hardwood seedling demand has increased, identifying effective means of assessing quality has become more important. An example of this growing demand may be seen in the Central Hardwood Region. In recent years, the 12 northeastern and midwestern states that comprise this region have been experiencing a severe shortage of hardwood seedlings. In 1999, it was estimated that demand outpaced supply by 25 to 50 million seedlings (Michler and Woeste 1999), with that demand expected to rise 20% annually. Rather than timber production, a major reason for this trend is concern over conserving soil and water resources and an interest in improving wildlife habitat through greater biodiversity, as evidenced by bottomland hardwood reforestation in the Lower Mississippi Alluvial Valley (King and Keeland 1999). Private landowners who outplant hardwoods are also interested in leaving a legacy for future generations (Ross-Davis and others forthcoming). The increase in hardwood production has prompted renewed interest in research programs and cooperatives that seek to advance regeneration and establishment practices. One such program is the Hardwood Tree Improvement and Regeneration Center (HTIRC). The HTIRC is a regional collaborative partnership between federal, state, university, and industry groups designed to expand basic and applied information about hardwood species. Programs such as these will concentrate on improving morphological, physiological, and genetic quality of hardwoods.

Hardwood and Conifer Differences

There are differences between conifers and hardwoods that affect approaches to quality assessment. Most conifers commonly used in forestry applications in the US belong to the Pinaceae family. Common hardwood species, on the other hand, are members of a number of different families: Aceraceae (*Acer*), Fagaceae (*Castanea* and *Quercus*), Hamamelidaceae (*Liquidambar*), Juglandaceae (*Carya* and *Juglans*), Magnoliaceae (*Liriodendron*), Oleaceae (*Fraxinus*), Platanaceae (*Platanus*), and Rosaceae (*Prunus*). Not only must one consider variation among species, but among families as well. Additionally, most hardwoods are broad leaved and deciduous, while most conifers have needlelike leaves and are evergreen. This can affect foliar analysis and diagnosis of problems associated with environmental stresses, particularly during the dormant months. Many hardwoods tend to exhibit more branching, have thicker roots, require higher fertility, and are more susceptible to pests and diseases when compared to conifers (Tinus 1978). All of these factors are important when developing appropriate protocols for evaluating hardwood seedling quality.

Another obstacle to overcome is lack of a substantial body of peer-reviewed scientific literature relative to that of conifers. There is need for rigorous statistical documentation of many issues related to hardwood regeneration. For instance, definitive guidelines describing optimal hardwood seedling morphological characteristics have not been published (Gardiner and others 2002).

Hardwood Seedling Quality

Morphological

Traditionally, seedling quality assessment of conifers has been conducted using morphological assessment. Morphological characteristics are easily and readily observed and measured (Ritchie 1984), making them more practical to use. Accordingly, morphology continues to be particularly useful for large scale grading. Many studies have evaluated variables such as height (Figure 1), stem diameter at root collar, root volume, fresh weight, bud size, and first order lateral roots (FOLR) for testing seedling quality of conifers (Kozlowski and others 1973; Reese and Sadreika 1979; Nambiar 1984; Rose and others 1991; Hallgren and others 1993; Ritchie and others 1993). Ratios of various morphological traits have also been considered (Bayley and Kietzka 1996). Not all of these variables are practical to implement on an operational scale; if superior predictors can be identified, it may be possible to modify cultural techniques to increase quality.

Hashizume and Han (1993) showed that the height of sawtooth oak (*Quercus acutissima* Carruth) seedlings was an important factor in determining growth and survival, with the tallest trees (>150 cm [59 in]) having lower survival percentages than trees 100 to 120 cm (39 to 47 in) in height. Thompson and Schultz (1995) found a negative correlation between initial height and first-year height growth of northern red oak (*Quercus rubra* L.), while the number of FOLR was positively and significantly correlated with height, diameter growth, and survival. In contrast, initial height of konara oak (*Quercus serrata* Thunb.) in Japan was positively associated with survival and weight after 5 years (Matsuda 1989).

Ruehle and Kormanik (1986) looked at FOLR as a possible indicator of northern red oak seedling quality. They found a significant correlation between the number of FOLR and height, as well as stem diameter and shoot and root mass. Kormanik and others (1995) mention positive correlations of FOLR with growth of northern red oak, white oak (*Quercus alba* L.), and sweetgum (*Liquidambar styraciflua* L.). Other studies have given mixed results about the usefulness of FOLR. Ponder (2000) showed positive correlations of FOLR with 4-year height growth of northern red oak and black oak (*Quercus velutina* Lam.) but no effect on growth of black walnut (*Juglans nigra* L.) and white oak. Data from Jacobs and Seifert (unpublished) indicated that FOLR was a poor predictor of height and diameter growth of northern red oak, white oak, and black cherry (*Prunus serotina* Ehrh.) after 1 year.

Figure 1—Measuring seedling height is a common method for morphological assessment.

Stem diameter, shoot length, and number of FOLR were correlated with second-year height and diameter of northern red oak 2 years after outplanting in Ontario, with initial stem diameter being the best predictor (Dey and Parker 1997). Stem diameter was also a good predictor of many root system traits such as volume, area, and dry mass. This is consistent with the results of Williams (1972) that showed that stem diameter was a better predictor of black walnut growth than root fibrosity. In the sweetgum research of Belanger and McAlpine (1975), the growth response of various root collar diameter grades was obvious after the first growing season and continued through the seventh season. At that point, trees from the largest seedling grade averaged 1.95 m (6.4 ft) taller than the trees from the smallest grade. Determination of various morphological ratios can also be an effective component of testing programs, providing an indication of balance between different plant parts. The root:shoot ratio is one of the most commonly used ratios. It is ratio of root mass to shoot mass and can often discriminate between high and low quality stock (Tomlinson and others 1996; Edwards 1998). This and other ratios, such as height:stem diameter, have not been extensively evaluated as potential quality indicators for hardwoods. Root volume, fresh weight, and bud size are among the many other traits that have been studied in conifers, but not to any significant extent with hardwoods.

Physiological

Differences in morphology often do not reflect variation in physiological condition. Morphological assessments of quality would have more validity if all the seedlings of interest were of the same physiological status. This may be the basis for much of the variation and inconsistency in past research (Ritchie 1984). Stone and Jenkinson (1971) found that ponderosa pine (*Pinus ponderosa* Douglas ex Lawson) seedlings of a high morphological grade might have a low root growing potential, even when outplanted into optimal growing conditions. If lifted and outplanted earlier or later, the same grade may have a high root growing potential. This result was best explained by differences in physiological status at time of outplanting. Because of results such as these, physiological quality testing has been gaining prominence. Physiological testing of conifers includes root growth potential (RGP), electrolyte leakage (EL), chlorophyll fluorescence (CF), water relations, nutrient status, enzymatic activity, and stress-induced volatile emissions (SIVE) (Landis 1985; McCreary and Duryea 1987; Orlander and Rosvall-Ahnebrink 1987; Lassheikki and others 1991; McKay 1992; Templeton and Colombo 1995; Mohammed and others 1997; Kooistra and Bakker 2002). These tests aim to quantify internal attributes such as stress resistance, dormancy status, and cold hardiness.

RGP testing (Figure 2) is by far the most common testing protocol (Simpson and Ritchie 1996). RGP is evaluated by placing seedlings in an optimal growing environment and assessing the initiation and elongation of new white roots (Sutton 1990). These tests can take weeks to complete, however. Rapid tests for estimating seedling physiological status are needed for nurseries to make timely management decisions on lifting, storing, and outplanting (Hawkins and Binder 1990). Recent research is evaluating these rapid methods. CF works on the concept that when plants are subjected to stress, changes in the photosynthetic pathways occur. Therefore, emission of light energy from the photosynthetic system varies according to the stress level. Using a chlorophyll fluorometer, this method is fast and nondestructive (Mohammed and others 1995). SIVE is a technique that has been the subject of recent research (Hawkins and DeYoe 1992; Templeton and Colombo 1995). It involves measurement of ethanol production from stressed seedlings. EL (Figure 3) has been used extensively for cold hardiness and dormancy status testing and is an indicator of cell membrane integrity and physiological activity. Mineral nutrition is important because it affects not only morphological characteristics such as height and root structure, but can indirectly affect indicators of physiological quality such as cold hardiness (Jozefek 1989). Tests of water potential and enzymatic activity are representative of the inherent stress resistance and viability of a seedling.

Figure 2—Evaluating root growth potential (RGP).

Figure 3—Electrolyte leakage (EL) from plant tissue samples.

Because of its potential in predicting field performance and improving establishment success in conifers, physiological quality testing has become operational practice in parts of the United States, Canada, Great Britain, and Sweden (Dunsworth 1996). There has also been an increase in research on physiological testing of hardwoods. O'Reilly and others (2002) employed an aerated hydroponics system to assess RGP of freshly lifted and cold stored ash (*Fraxinus excelsior* L.) and sycamore (*Acer pseudoplatanus* L.), where RGP was significantly correlated with height of freshly lifted ash after 1 growing season in the field. In the same experiment, shoot water potential (WP) and root electrolyte leakage (REL) were assessed for both species and storage regimes. WP was significantly correlated with height increment of cold stored sycamore; however, REL showed no significance for any variable. RGP has also been used successfully to predict field performance of European white birch (*Betula pendula* Roth.), English oak (*Quercus robur* L.) (Lindqvist 1998), and Holm oak (*Quercus ilex* L.) (Pardos and others 2003), with the highest RGP values related to increased growth and survival.

Stem WP was an effective predictor of field performance of European wild cherry (*Prunus avium* L.) and cherry plum (*Prunus cerasifera* Ehrh.) after 1 growing season (Symeonidou and Buckley 1999). WP has also shown positive correlation with RGP readings at outplanting for various hardwoods such as sugar maple (*Acer saccharum* Marsh.), silver maple (*Acer saccharinum* L.), paper birch (*Betula papyrifera* Marsh.), white ash (*Fraxinus americana* L.), black walnut, and northern red oak (Webb and von Althen 1980). In Symeonidou and Buckley's cherry study (1999), stem WP was compared with other physiological testing methods: REL, tetrazolium absorbance, and root moisture content (RMC). All methods were effective predictors of eventual plant performance. The main difference among the methods was cost effectiveness, with REL and RMC being the least costly. Tetrazolium testing and WP required more sophisticated equipment. In another comparative study, Radoglou and Raftoyannis (2001) evaluated REL, WP, and RMC of fine roots. For sycamore, flowering ash (*Fraxinus ornus* L.), and Spanish chestnut (*Castanea sativa* Mill.), REL values were significantly related to field performance of seedlings exposed to both freezing temperatures and desiccating conditions. WP and RMC were significantly predictive only in the desiccation treatment. Nutrient and foliar analysis, SIVE, and CF have been little used in the context of evaluating field performance potential of hardwoods, particularly because of problems associated with the deciduous nature of most hardwood species.

Future Directions

Future hardwood seedling quality research will face many challenges, but there are steps that can be taken to ensure successful and productive information exchange between practitioners and researchers. It is important to start with the most commonly produced species and consider the ability to transfer information to other species and families. However, it is likely that variable solutions exist for different species. Hardwood species also favor a number of different ecotypes. It is crucial to document site characteristics and replicate across other sites as needed. Lack of leaves is another consideration. It will be necessary to adjust timing and methodology of sampling procedures to account for this absence. An integrated approach to quality assessment will be needed to account for the many cultural and environmental variables responsible for changes in hardwood morphology and physiology.

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