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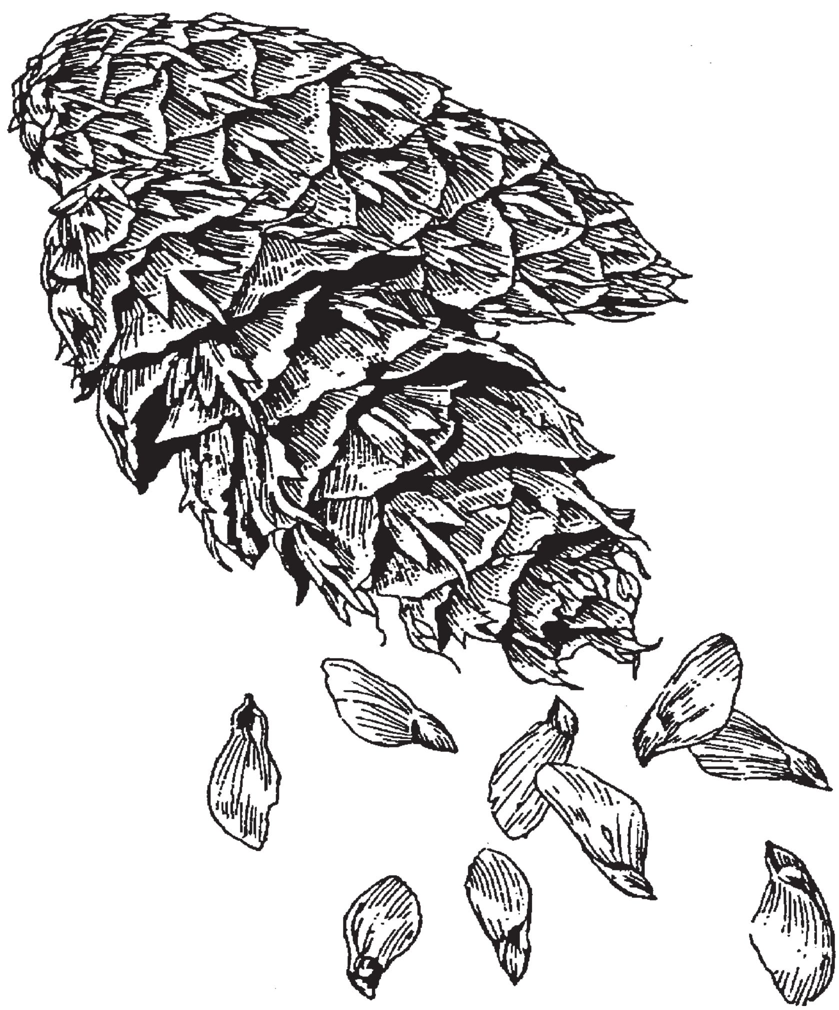

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Abstract

This proceedings is a compilation of 24 papers that were presented at the regional meetings of the forest and conservation nursery associations in the United States in 2005. The **Western Forest and Conservation Nursery Association** meeting was held at the Yarrow Resort Hotel and Conference Center in Park City, UT, on July 18 to 20. The meeting was hosted by the Utah Division of Forestry, Fire, and State Land, Lone Peak Nursery. Morning technical sessions were followed by field trips to restoration projects on the middle reach of the Provo River, McAffee Hill, and Dry Canyon, as well as tours of the Swaner Nature Preserve outside Park City, UT. Subject matter for the technical sessions included restoration outplanting, native species propagation, bareroot and container nursery culturing, greenhouse management, and gene conservation.

The **Northeastern Forest and Conservation Nursery Association** meeting was held on August 1 to 4 at the University Plaza Hotel in Springfield, MO. The meeting was hosted by the Missouri Department of Conservation, George O. White State Forest Nursery. Technical sessions were followed by tours of the Hammons Products Company walnut processing facility and Hammons Sho-nuf Walnut Plantation in Stockton, MO, and the George O. White State Forest Nursery in Licking, MO. Subject matter for the technical sessions included bareroot and container nursery culturing, hardwood management, and insect and disease monitoring.

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 Meeting

Park City, Utah

July 18–20, 2005

Strategies for Seed Propagation of Native Forbs

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Abstract: Native forbs are an increasingly important component of container production for many public and private nurseries. Propagators are often called upon to grow species with unknown requirements. A systematic approach is required to obtain plants from seeds of these species, beginning with determining what is a propagule and evaluating seed quality. Next, seed dormancy status must be determined, and appropriate dormancy-breaking treatments applied. Finally, germinable or germinated seeds must be sown into a propagation system that maximizes chances of survival and growth. The propagation system may need to be tailored to the requirements of the species being grown. Most native forbs can be grown successfully in containers, but a few present seed dormancy or seedling growth problems that we have not yet learned to overcome.

Keywords: dormancy, dry after-ripening, germination, hard seed, seed quality, stratification, viability

Introduction

The native flora of North America includes a wealth of broadleaf herbaceous species commonly referred to as forbs. Many of these forb species are coming into nursery production. Forbs are increasingly recognized as important components of the biodiversity of natural ecosystems, and they are frequently included in ecological restoration efforts. In addition, many forbs are traditionally recognized as medicinal plants whose over-collection in the wild is leading to efforts to establish them in cultivation. Native forbs also offer exciting possibilities for horticultural use as drought-tolerant, low-maintenance ornamentals. All of these factors play into the fact that many propagators are faced with the need to propagate forb species with unknown requirements.

In contrast to most species with a long history of cultivation, native forb species often have seeds that are not readily germinable. Seed dormancy mechanisms operate in nature to maximize chances of seedling survival by limiting germination to a favorable season or by spreading germination across years. Many cultivated species have wild ancestors whose seeds show these adaptive dormancy release patterns. A few generations in cultivation, however, are often sufficient to apply selection, either inadvertently or deliberately, for reduced dormancy. Consequently, propagators who have worked mainly with cultivated plants are often not prepared for the sometimes elaborate and time-consuming measures needed to overcome dormancy in the seeds of wild plants.

Components of a Forb Seed Propagation Strategy

Fortunately, there is some rhyme and reason to patterns of dormancy release in native forb seeds. By examining seed traits, family relationships, and habitat of origin for a particular seedlot, it is often possible to narrow down the possibilities for dormancy-breaking treatments. Approaching the problem systematically usually makes it possible to obtain plants within a reasonable amount of time. The key components to this approach are: determining what is a propagule, checking seed quality, determining seed dormancy status and germination requirements, and addressing seedling growth needs.

Determining What Is a Propagule

While the step of determining what is a seed or propagule may seem self-evident to some, a paper bag containing seeds of a wild-collected forb usually contains far more than the seeds in question. This is especially true if the collection was made by an inexperienced person, as is often the case with native forbs. The first task, even before seed cleaning, is to determine exactly what subset of the seed collection actually consists of seeds or propagules. The term propagule includes seeds, but also includes fruits that contain seeds, or seed-containing fruits with accessory floral structures. It refers to the unit that is capable of producing a seedling.

In trying to determine exactly what is the seed or propagule for a collection of an unfamiliar forb, the best first step is usually a quick perusal of a taxonomic description for the genus. This will determine, for example, whether the fruit is a capsule that must be ruptured to extract the seeds or a one-seeded fruit that is best handled intact. It will also give some information about seed size, which will determine whether to look for the seeds in the dust at the bottom of the bag or in the chunky debris on top of the coarsest screen. Once some of the attributes of the seeds and fruits are known, it is time to rummage around in the bag or dump it into a tray and attempt to find some propagules. Knowing what they look like before commencing seed cleaning can prevent embarrassing mistakes, such as throwing out the *Penstemon* seeds and saving the capsule partitions to plant, as has happened to at least one inexperienced student technician.

It is not always clear whether seeds need to be removed from their fruits prior to planting, especially for one-seeded fruits. For example, it is evident that the hard, one-seeded fruit of *Mirabilis multiflora* (desert four o'clock) constitutes a propagule, but in the related genus *Abronia* (sand-verbena), the wall of the fruit is papery and easily removed by threshing. Moreover, many of the papery fruits are not filled, so that threshing out the seeds results in a much higher quality lot that can be treated and sown with more precision. In the sunflower family, on the other hand, the one-seeded fruits are always treated as propagules, although the accessory floral structure (pappus) is often removed by rubbing to facilitate handling.

Checking Seed Quality

Usually when seeds are cleaned, most of the unsound or empty seeds are removed so that the cleaned lot is of relatively high quality. This is not always the case, however, and it pays not to assume that the seedlot at hand actually contains a high proportion of viable seeds. One can waste a lot of time and effort trying to get empty seeds to germinate, and the results are disappointing at best. The simplest method of checking seed quality is the cut test. If the seeds are recently harvested and have been dried and stored correctly (that is, not placed directly into sealed plastic bags), a cut test is a good estimate of viability. It consists of placing the seeds on a moist medium for a few hours until they imbibe water (after nicking, if they happen to be hard-seeded; see below), then bisecting them longitudinally with a sharp razor blade. Generally, if the seeds are hard and pale inside, and cut with a nice "vegetable crunch," they are (or were) alive. To make sure, one can dissect out the embryo and see if it has all its parts, especially a firm, white radicle (seed root) end. A shriveled radicle end means an effectively dead seed, while a little discoloration or deformity on the edges of the cotyledons (seed leaves) may have little effect on viability. If the seed goes squish when cut or contains a pulpy, soft, discolored embryo, it is not viable. Of course, if there is no embryo to be found, the seed is empty and, therefore, not viable.

It helps to know something about the seeds produced by plants of different genera. Seeds of the genus *Penstemon*, for example, are small and have a corky, air-filled outer seed coat. They contain mostly endosperm, with a small, sausage-shaped white embryo up the middle. The translucent, wax-like endosperm can be quite firm. If the white embryo is missing, however, the seed is not viable. Seeds of legumes like *Lupinus*, on the other hand, have very large embryos that completely fill the seed, so that it is easy to see whether or not they are "home" by slitting the seed coat and slipping the embryo out.

It is a good idea to cut at least 10 seeds to get a crude viability estimate. It takes more seeds to accurately assess the viability of a low-quality lot. If several of the first 10 seeds are not good, evaluate at least another 10. Formal quality evaluation includes four replications of 100 seeds each. But it is not necessary to sacrifice nearly that many seeds in order to get a rough idea of seedlot viability for practical purposes; when seed quantity is extremely limited, sacrificing even 10 seeds may seem ill-advised.

It sometimes happens that seeds are filled and can pass muster in a cut test, but are still not viable. Seeds that have been stored dry for such a long time that they have lost viability in storage fall into this category, as do seeds that have been stored for even a short time at a too-high moisture content (as in those plastic bags mentioned above) or temperature. Pathogenic storage fungi begin to operate at relative humidities in excess of 75 percent, which corresponds to a seed moisture content of about 14 percent. Seed viability will drop off rapidly under these conditions. If there is any question of viability loss in storage, it is worth performing a slightly more elaborate viability evaluation. Tetrazolium staining is the usual procedure (Peters 2000). This vital stain turns red in the presence of enzymes that occur in respiring, living tissue. To perform a tetrazolium test, the seeds are set to imbibe as in a cut test and are then pierced to allow entry of the large tetrazolium molecules, or the embryos are dissected out of the seeds. They are then immersed in the tetrazolium solution for several hours (warm temperatures hasten the process), then bisected (if seeds are intact) and scored by examining the staining patterns on the embryos. If the embryo stains completely bright red, the seed is unequivocally viable, while failure to stain indicates lack of viability. It takes some skill and experience to interpret tetrazolium staining, and some seeds stain better than others. *Penstemon* seeds, for example, often do not stain very darkly, even if highly viable as determined in concomitant germination tests. Still, a tetrazolium test is more definitive than a cut test as a viability evaluation procedure, and is sometimes accepted as an official surrogate for a germination test in the quality evaluation of highly dormant species.

Even if a seedlot shows low viability as determined by a cut test or tetrazolium staining, it may still be possible to obtain plants, as long as seed supply is not limiting. Knowing the approximate proportion of viable seeds makes it possible to estimate how many total seeds might be needed to obtain a given number of plants. Or it may sometimes be possible to clean the lot more vigorously, with a seed blower for example, to increase the proportion of filled seeds.

Determining Dormancy Status and Germination Requirements

There is a very extensive literature on the subject of seed dormancy and germination, including a plethora of different dormancy classification schemes (Baskin and Baskin 1998). From the point of view of propagation, the most useful scheme is one that is centered on treatments required to break dormancy rather than on its anatomical, developmental, and physiological causes. Such a practical seed dormancy classification scheme is adopted here:

1) Seeds nondormant. Seeds germinate readily over a wide range of conditions, and no dormancy-breaking treatment is required. Predicting which species will have nondormant seeds is a gamble, but experience has revealed some patterns. For example, small-seeded members of the Asteraceae (sunflower family) almost always have nondormant seeds, as do members of the genus *Asclepias*. Within a genus, seeds from low elevation species and populations are more likely to be nondormant than seeds from high elevation.

2) Seeds conditionally dormant. Seeds germinate only under a narrow range of conditions, behaving as if dormant unless these conditions are met. Sometimes conditionally dormant seeds can become nondormant through the application of dormancy-breaking treatments, but these are not necessary as long as specific germination conditions are met. An example of conditional dormancy is found in many species of freshwater marshes, where widely fluctuating temperatures provide a cue that water levels have dropped to the point that seedling establishment is possible. The seeds will not germinate at any constant temperature. Similarly, a light requirement for germination is characteristic of many weedy species of arable land. Light provides a cue that soil disturbance has returned the seeds from depth to a position at or near the surface, where establishment is possible. The light requirement in weeds is usually coupled with specific temperature requirements for germination that exhibit cyclic changes, but such mechanisms are much less common in native forbs.

3) Seeds physiologically dormant, losing dormancy through dry after-ripening. Seeds are dormant at harvest and lose dormancy in dry storage. Often they proceed from dormant to conditionally dormant to nondormant during this process. The rate of dormancy loss in dry storage is directly related to temperature, and for some species dormancy loss is very slow except at high temperature. Many seeds thought of as nondormant actually exhibit dormancy or at least conditional dormancy at dispersal, but quickly become nondormant through dry after-ripening under summer conditions. These seeds also lose dormancy in laboratory storage, albeit more slowly. Many grass species follow this pattern, which is generally characteristic of species whose seeds are produced in early summer and whose seedlings are autumn-emerging.

4) Seeds physiologically dormant, losing dormancy through cold or warm plus cold stratification. Seeds of a large number of species of temperate regions are dormant at harvest and lose dormancy under cold, wet conditions that simulate winter. This ensures that germination will not take place before the onset of winter, but will instead occur in late winter or spring, when conditions for establishment are most favorable. Rate of dormancy loss is essentially constant over the chilling temperature range 0 to 5 °C (32 to 41 °F), but dormancy loss generally stops at temperatures above or below this range. Examples of native forbs with chilling-responsive seeds include most of the large-seeded members of the Asteraceae and most members of the Scrophulariaceae (snapdragon family), Boraginaceae (borage family), Polemoniacaeae (phlox family), Apiaceae (parsley family), Polygonaceae (buckwheat family), and Liliaceae (lily family).

The length of chilling necessary to break dormancy varies among species, among populations within species, and among seeds within a lot. In general, the chilling requirement tends to increase with increasing elevation, which makes sense because winters are longer in the mountains. Chilling requirements of 6 months or more are not unusual for high mountain species such as scarlet paintbrush (*Castilleja miniata*), mountain bluebells (*Mertensia ciliata*), and Whipple penstemon (*Penstemon whippleanus*), which inhabit places where snow pack lingers into the summer. Foothill species and populations of *Penstemon* may require 3 or 4 months of cold stratification, while seeds of lower elevation desert species and populations may respond to stratification periods of only a few weeks (Meyer and others 1995).

Seeds of some species require a period of warm, wet conditions prior to cold stratification in order to lose dormancy during chilling. Seeds with immature embryos that require warm plus cold stratification to induce embryo growth and germination are included here. There are relatively few native western forbs known to have a requirement for warm plus cold stratification. Seeds of baneberry (*Actaea rubra*) and of some forest-dwelling members of the Liliaceae may respond to this treatment.

5) Seeds physically dormant, requiring seed coat breaching to imbibe water. Seeds at harvest are "hard" and unable to take up water. They will germinate readily, usually over a wide range of conditions, once the integrity of the seedcoat is breached. True "hard-seededness" requires very specialized cellular development within the seedcoat and is confined to only a few plant families. North American families with hardseeded forb species include the Fabaceae (pea family), Convolvulaceae (morning glory family), Cucurbitaceae (gourd family), Malvaceae (mallow family), and Geraniaceae (geranium family). To break physical dormancy, the seed coat is usually disrupted using mechanical methods such as nicking or sandpaper, acid scarification, or heat treatments such as a boiling water soak. It is important that these treatments be carefully applied, or the embryo may be damaged.

6) Seeds with multiple dormancy mechanisms. Species with multiple seed dormancy mechanisms fall into two categories, those whose seeds require a specific sequence of dormancy-breaking treatments and those whose seeds lose dormancy in response to different dormancy-breaking treatments applied singly. Hardseeded species like *Astragalus utahensis* (Utah ladyfinger milkvetch), whose seeds usually require cold stratification after hardseededness is broken, exhibit a requirement for a specific sequence of dormancy-breaking treatments. Seeds of some populations of *Linum lewisii* (Lewis flax) are dormant at harvest but can lose

dormancy either through dry after-ripening or through cold stratification. They represent seeds that can lose dormancy through multiple pathways.

7) Seeds with cue nonresponsive dormancy. Some native forb species have seeds that are programmed for persistence in the soil seedbank for long periods of time. Many hardseeded species fall in this category. However, because their physical dormancy is easily broken, they are usually not too hard to propagate. Other species have physiological dormancy that is not broken by any of the dormancy-breaking treatments that correspond to environmental cues such as dry heat or cold stratification. Most of the seeds in a population are programmed to ignore these cues, with only a small fraction becoming cue-responsive each year.

Species with cue nonresponsive seeds can be difficult to propagate. One method that has been effective involves injuring the seeds, for example by piercing, which seems to disrupt their ability to remain dormant. This is similar to mechanical scarification of hard seeds, but seeds of these species readily take up water. Sometimes such damage to imbibed seeds will induce immediate germination, and sometimes it will render the seeds responsive to cold stratification. Another method that is sometimes used is the application of a plant hormone such as gibberellic acid (GA_3), which can also induce immediate germination or increase chilling-responsiveness (Kitchen and Meyer 1991). A disadvantage to this latter method is that the resulting seedlings tend to be etiolated. Careful attention to GA_3 concentration and to handling of the resulting seedlings can result in successful propagation. Unfortunately, many species with cue nonresponsive dormancy do not respond to GA_3.

Variation in Dormancy-Breaking Requirements—One of the hallmarks of natural populations of plants is variation, and this applies to traits associated with seeds as much as those associated with actively growing plants. This variation is grist for both natural and artificial selection, but it can be quite a nuisance for the propagator. Successfully propagating a species from one seedlot is no guarantee that the method employed will work with other collections of that species. Among-population differences in seed dormancy status were mentioned in the section on cold stratification. Such variation makes it difficult to generalize about germination requirements for many native species. In *Penstemon palmeri*, for example, dormant lots may respond positively to cold stratification, while nondormant lots actually tend to go into secondary dormancy following the same treatment (Meyer and Kitchen 1992).

Even more troublesome to the propagator than dormancy variation among different seedlots is dormancy variation among individual seeds within a seedlot. For example, for propagation of chilling-responsive species, the desirable scenario is for all the seeds to have the same cold stratification requirement and for none of the seeds to germinate during chilling. Unfortunately this is rarely the case for native forbs. Most have seeds that germinate in chilling soon after they become germinable at higher temperature. And the chilling requirements for individual seeds vary widely, so there is no one chilling time when the majority of ungerminated seeds can be removed from stratification, planted, and expected to emerge.

In addition to simple variation in the chilling duration required to break dormancy, an added difficulty for many species is the presence of a sometimes sizeable fraction of seeds that are cue nonresponsive and do not germinate even after very long chilling periods, much longer than the duration required for germination of the cue-responsive fraction of the seedlot. These seeds are clearly programmed not to germinate in response to the first winter they experience. Sometimes it is possible to get another pulse of germination out of such a seedlot by drying the stratified seeds for a few weeks, then placing them back into cold stratification. This may in effect trick the seeds into responding as if a summer had passed and a second winter had commenced.

A Decision Tree for Approaching Seed Propagation of a Forb With Unknown Requirements—Once seeds are identified, cleaned, and checked for viability, the first question to address is whether they can take up water (figure 1). Again, this is only an issue for seeds of species that belong to the families where hardseededness is a possibility. If hardseededness is present, the next step is to scarify a few seeds and determine whether they are rendered readily germinable under laboratory conditions. If the answer is yes, then the lot needs scarification as the only dormancy breaking treatment prior to planting. If the answer is no, then the scarified, imbibed seeds should be subjected to cold stratification. Usually a short chill (2 to 4 weeks) is sufficient to remove physiological dormancy of formerly hard seeds.

For lots that are not hard-seeded, the obvious next question is whether the seeds are nondormant, that is, whether they can germinate without any dormancy-breaking treatment (figure 1). If seeds that are imbibed and placed under laboratory conditions germinate to high percentages within 1 to 3 weeks, the lot can be considered nondormant and can be direct-sown without treatment. Even seeds that are conditionally dormant will usually germinate within a few weeks under conditions of moderate alternating temperatures (for example, 10 to 20 °C [50 to 68 °F]) and fluorescent light. This is the regime we use to define provisional dormancy status. Incandescent light can inhibit germination of light-requiring seeds, and high temperatures (>25 °C [77 °F]) are almost universally inhibitory to forb seed germination. To determine whether the seeds require light to germinate, place a container of imbibed seeds in the dark (aluminum foil works for this purpose) and compare germination success with seeds incubated under fluorescent light.

If seeds are dormant, there are two principal options for breaking dormancy, and if seeds are plentiful, it is usually wise to pursue both of these options simultaneously (figure 1). One subset of seeds can be placed in warm dry storage to hasten dormancy loss through dry after-ripening. Air-dry seeds can be placed in a sealed container, such as a screw-cap vial, and stored at temperatures as high as 40 °C (104 °F) for a few weeks without damage. Even storage at 30 °C (86 °F) will greatly hasten dormancy loss, and is less risky for low-vigor lots that may be more susceptible to heat damage. If controlled temperature, warm storage conditions are not available, the back seat of a car parked outside in summer or on top of the furnace in winter are reasonable substitutes. If these temperatures seem excessive, consider that summer soil seed bed temperatures in desert ecosystems commonly reach 50 °C (122 °F) for several hours during the day and

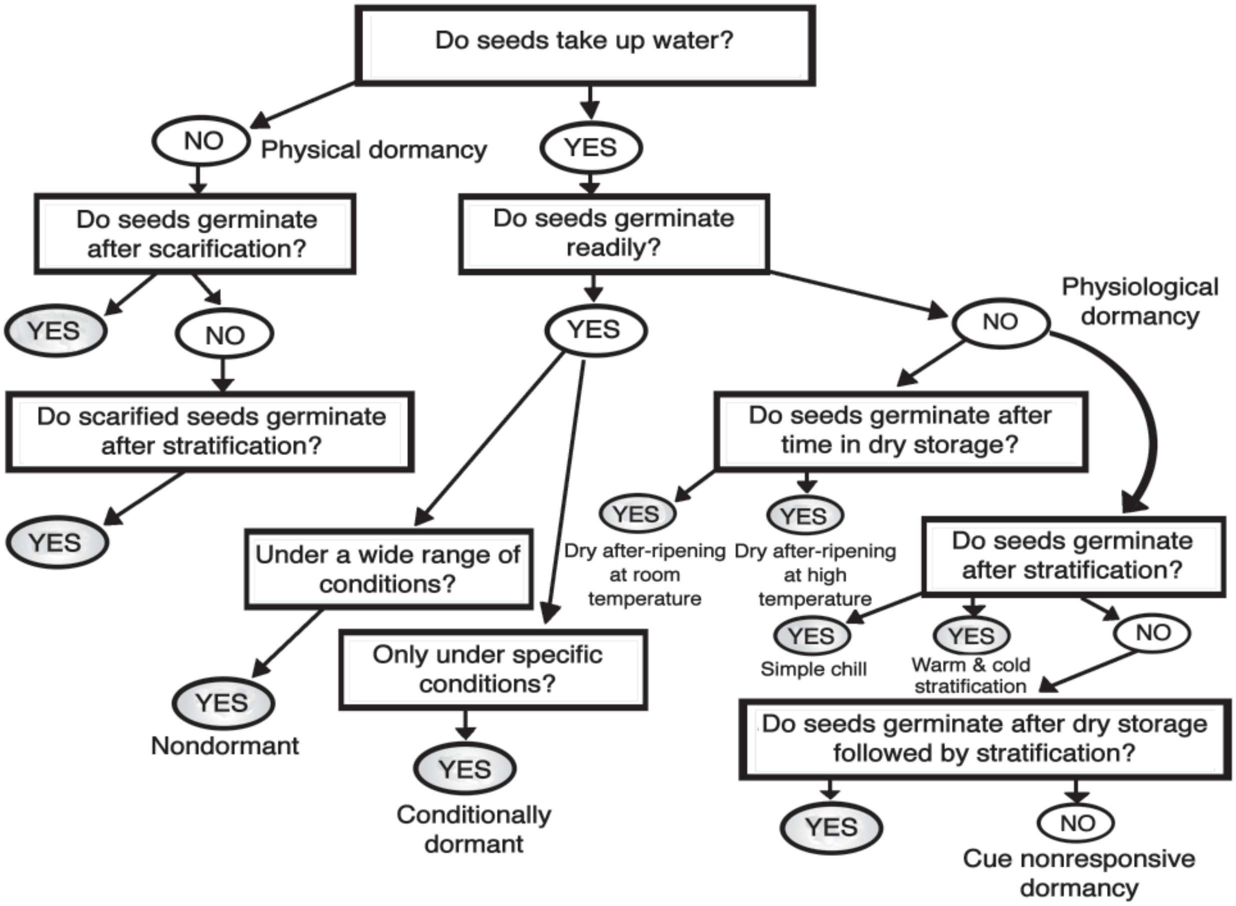

Figure 1—A decision tree for approaching the seed propagation of a native forb with unknown germination requirements.

may go as high as 60 °C (140 °F). The stored seeds should be retested for dormancy status at weekly intervals. If no change is observed after a month or more of warm dry storage, the seeds probably do not lose dormancy through dry after-ripening.

A second batch of seeds can be placed directly into cold stratification (figure 1). Small numbers of seeds can be pulled out of chilling at intervals and germinated under laboratory conditions to check for dormancy status. Depending on species and habitat of origin, chilling periods of 6 months or more may be required. The seeds in chilling should be checked frequently, however, as many species have seeds that will germinate during chilling once dormancy is alleviated. Germinated seeds need to be planted right away. If they are left too long in the cold, the radicles elongate to the point that planting the seedlings without damage becomes impossible.

A third option for seeds that apparently do not dry after-ripen is to take batches of seeds that have been subjected to warm, dry storage and place them into cold stratification. Even though the seeds have not been rendered nondormant in warm, dry storage, their chilling requirement may have been shortened considerably.

A fourth option is to place dormant seeds that have been incubated at room temperature for a few weeks into cold stratification. This is equivalent to applying a warm plus cold stratification treatment. It is most likely to work with species from summer-moist, mountain, or forest environments.

If none of the treatments described above result in significant germination of a viable seedlot, it is likely that the seeds exhibit cue nonresponsive dormancy, and more drastic dormancy breaking methods are in order. Combining seed coat injury, GA_3 treatment, or drying with cold stratification may alleviate dormancy in some cue nonresponsive lots.

Addressing Seedling Growth Problems

For most native forbs, obtaining germination is the most difficult phase of the propagation process. Some species, however, present serious problems at the post-seedling stage. These generally fall into two categories: problems related to pathogens and symbionts, and problems related to intrinsic growth attributes of the plant.

Seedling Growth Problems Related to Pathogens and Symbionts—Damping-off or root diseases can be a problem in any seed propagation effort, but this problem is generally more acute with native forb species, especially those from dry environments. Using good phytosanitary practices and aerated steam-treated potting medium can certainly help. Coarse, fast-draining mixes and top-dressing with sand can also help protect the young plants from the wet crown conditions that predispose them to disease. Including some field soil in the potting mix can also be an important disease deterrent. Field soils often contain antagonistic organisms like actinomycetes that can decrease the severity of many seedling diseases (Weller 1988). Finally, chemical fungicides may be used, but these must be applied with caution as native forb seedlings often exhibit fungicide toxicity symptoms much more readily than the crop plants for which these fungicides were developed.

Adding field soil to the potting mix may have other benefits as well. For legumes capable of forming symbiotic relationships with nitrogen-fixing organisms, field soil from the root zone of wild individuals of these species can provide the inoculum needed to form these associations. There is evidence that creating such symbiotic nitrogen-fixing associations in containers produces healthier plants than simply providing an abundance of available inorganic nitrogen.

Another class of symbiotic organisms, endomycorrhizae, can also be provided to container plants through the use of field soil in the potting mix or commercially available inoculum. Almost all native forbs form mycorrhizal associations (Smith 1996). Mycorrhizal organisms aid the plant in several ways. In addition to increasing uptake of relatively nonmobile nutrients like phosphorus by increasing the effective root area and extent, mycorrhizae also improve water relations, and can also protect the roots from harmful organisms in the root zone. This last effect may be the most important benefit for plants in containers, where nutrient and water resources are generally not limiting, but the other benefits are often evident after outplanting.

Seedling Growth Problems Related to Intrinsic Growth Attributes—Problems related to intrinsic growth attributes of a particular species are inherently more difficult to deal with than those involving interactions with other organisms, which can be often mitigated by managing cultural conditions. Intrinsic growth attributes that cause problems in container culture include features of root architecture and phenology of shoot growth.

Fibrous-rooted plants are much easier to produce in containers than tap-rooted plants for at least two reasons. They do not require deep containers as seedlings, and they quickly form a coherent root ball that makes transplanting easy. Fortunately for native forb growers, many timber tree species are taprooted as seedlings. The problem of container shape has already been resolved, and there are many useful variations available in the trade. The important thing is to recognize which forb species require deep containers. For example, *Astragalus* (milkvetch) species tend to be strongly taprooted and hardly progress past the seedling stage when planted in shallow flats. Even in deep containers, it takes a long time for them to develop a lateral root system than holds the planting medium together during transplanting. Using containers like Spencer-Lemaire Root Trainers™ (Spencer-Lemaire, Edmonton, Alberta, Canada) that open up for seedling removal can reduce wear and tear on weak root systems during transplanting. An alternative is to use a stabilized medium such as a Q-Plug™ (International Horticultural Technologies, Hollister, CA), which retains its shape upon removal from the container and can protect the roots of weakly rooting forbs during transplanting. We definitely need more research on methods for increasing lateral root development in slow-growing, taprooted species.

Even more problematic than taprooted plants like *Astragalus* species, which at least continue active growth in containers for an indefinite period of time as long as conditions are favorable, are species that combine the deep-rooted habit with summer dormancy. Many of the most beloved western wildflowers, including some native lilies, belong in this category. The seeds are generally fairly easy to germinate, requiring only cold stratification, and the seedlings emerge readily and begin growth. But after a few weeks, and usually after the production of a only single true leaf, growth ceases and the plants go into dormancy, even if conditions remain apparently favorable.

Plants with the summer-dormant pattern of growth are usually found in desert and foothill habitats where summers are dry. In nature, they have everything to gain by spending their energy building roots to get through the summer rather than leaves, which are destined to wither quickly in any case. Such plants are often long-lived and require many years to reach flowering size. For example, species of desert parsley (*Lomatium*) follow this summer-dormant pattern. Cow parsnip (*Heracleum lanatum*), a relative from the mountains, is much easier to grow in containers. It continues shoot growth all summer in the cooler, wetter mountain environment where capitalizing on leaves to maximize light capture is the best strategy. Other examples of summer-dormant forbs are balsamroots (*Balsamorhiza*) and foothill species of waterleaf (*Hydrophyllum*) and bluebell (*Mertensia*).

One thing that makes summer-dormant plants so difficult to handle in containers is that, once the plant is dormant, it is difficult to know how much to water. Clearly, too much water will cause the roots to rot and die; no water at all over a long period of time in a container not in physical contact with the soil may be equally damaging. Also, we do not know how to bring these plants back out of dormancy. In some cases, a dry-down may be sufficient for the plants to reinitiate growth. But many of these plants do not grow at all in autumn in nature, no matter how much it rains. This suggests that they may need cold stratification to break bud dormancy and reinitiate growth. If this is true, it may be possible to speed growth by putting the plants through multiple simulated springs (temperate and moist), summers (dry), and winters (cold and moist) in a single year. To my knowledge, no one has tried to do this systematically, but it is certainly an area that would benefit from serious research. From a restoration standpoint, it might be sufficient just to plant out the dormant first-year seedlings and let nature take its course.

Conclusions

Seed propagation of native forbs is one of the most satisfying activities available to plant propagators. By following a systematic protocol for determining germination and growth requirements, it is usually possible to obtain plants in a reasonable period of time. Native forb species present a variety of problems, but it is most intriguing to work with these plants and solve the problems they present. It is hard to match the thrill of producing healthy container stock of a species that may never have been seen before except in the wild. If one can follow the temptation to take some of these container-grown plants and place them in a horticultural setting, the interest level increases even further. The reward may be an outstandingly beautiful plant worthy of display in the garden of even the most demanding flower connoisseur.

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Revegetation Strategies and Technologies for Restoration of Aridic Saltcedar (*Tamarix* spp.) Infestation Sites

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Abstract: Critical knowledge gaps exist regarding vegetative recovery in aridic, monotypic saltcedar (*Tamarix* spp.) stands with no desirable understory plants. Formulation of revegetation strategies that provide site stabilization, resistance to further saltcedar and secondary weed infestation, and acceptable habitat values for affected wildlife species becomes particularly problematic in monotypic saltcedar stands under biological, fire, and herbicidal (that is, nonmechanical) control scenarios. Amount and density of standing biomass (live and dead) remaining after control pose limitations in relation to seeding and outplanting techniques, seed interception in aerial (broadcast) applications, and seedbed preparation methods. Undisturbed soil surfaces impacted by saltcedar leaf litter accumulation, salinity, hummocky micro relief, and nutrient limitations restrict potential for successful revegetation. Long duration of saltcedar occupation may deplete desirable microbial communities, particularly arbuscular (endo)mycorrhizae symbiotic and host-specific to native revegetation species. Selected results of innovative revegetation strategies at study sites on the Rio Grande and the Colorado River are discussed. Technical approaches include: 1) soil surface and rhizosphere manipulation methods to facilitate removal of standing dead biomass, increase precipitation capture, improve soil moisture retention, and create microsites exhibiting lower salinity and increased protection from environmental extremes for improved seed germination; 2) salinity remediation using HydraHume™; 3) seeding methodologies, including use of seed coating techniques; and 4) mycorrhizal inoculation methods.

Keywords: seedbed manipulation, mycorrhizal inoculation, triclopyr, mulching, *Atriplex*

Introduction

Executive Order 13112 (Invasive Species) mandates that Federal agencies control and monitor invasive species, provide restoration of native species and desirable habitat conditions in ecosystems that have been invaded, and conduct research to develop technologies to prevent introduction and provide environmentally sound control of invasive species. Unfortunately, research is often driven by evaluation of control measure effectiveness, with secondary emphasis on ability of sites to sufficiently recover vegetatively for site stabilization and habitat value enhancement (Anderson and Ohmart 1979; DeLoach and others 2000; Lair and Wynn 2002). On xeric, saline sites not subject to seasonal flooding, recovery of desirable vegetation may be the most limiting factor for site enhancement (Anderson 1995).

Tamarix L. spp. (saltcedar) is a highly invasive exotic shrub that has invaded thousands of acres along many major river systems (Crawford and others 1993; USBR 2000; McDaniel and others 2000). Throughout the Western United States, saltcedar infestation has been documented to produce adverse environmental effects in riverine and lacustrine systems. These effects include increased wildfire potential resulting from high densities of fine, woody fuel materials; significant reduction in biodiversity, wildlife habitat, and riparian ecosystem function and structure; and significant reduction of surface and groundwater return flows (Crawford and others 1993; Anderson 1995; DiTomaso and Bell 1996; CEPPC 1998; Zavaleta 2000a,b). Saltcedar spreads by seed dispersal and vigorous sprouting from lateral roots and decumbent stems (that is, prostrate stems with nodes in contact with the soil surface), competitively and rapidly displacing native stands of cottonwood (*Populus* L. spp.), willow (*Salix* L. spp.), and grasses that are more fire-resistant (Warren and Turner 1975; Anderson and Ohmart 1979; Lovich 1996; Wiesenborn 1996).

Saltcedar has been implicated in severe reduction of habitat value within the riparian corridors of major river systems (Anderson and Ohmart 1979; Crawford and others 1993; Anderson 1995). Minimum flow volumes within the middle Rio Grande River have recently been mandated as critical for maintenance of an endangered fish, the Rio Grande silvery minnow (*Hybognathus amarus* Girard). Saltcedar has also been suggested as a possible cause of habitat reduction along the Canadian River system for many native fish and wildlife species, including the endangered Arkansas River shiner (*Notropis girardi* Hubbs & Ortenburger) (Eberts 2000; Davin 2003). One implication of this requirement is that additional water (via surface and groundwater return flow contributions) will be needed to support improved habitat for this fish. Landscape-scale management of saltcedar could positively address this need because of saltcedar's phreatophytic growth regime, high consumptive use (evapotranspiration) rate, high stand densities, and increasing infestation extent. Similarly, adverse impacts of saltcedar infestation on habitat of the southwestern willow flycatcher (*Empidonax traillii* ssp. *extimus* Audubon) have been well documented (Anderson and Ohmart 1979; Carpenter 1998; DeLoach and others 2000; Dudley and others 2000; Zavaleta 2000a,b).

Fire prevention and management in natural areas is exacerbated in dense saltcedar stands (Friedman and Waisel 1966; Busch 1995; Scurlock 1995; Wiesenborn 1996; Zavaleta 2000a). Saltcedar is a multi-stemmed invasive (exotic) shrub, sprouting basally from the root crown and lateral roots (DiTomaso 1996; Carpenter 1998). It can produce near continuous cover, ladder fuel structure, and extremely high standing biomass of fine to medium, woody fuel material (Busch 1995; Wiesenborn 1996). In dense, monotypic stands, mean canopy height can exceed 12 m (39 ft), with canopy closure (aerial cover) often approaching 100 percent (Lair and Wynn 2002), resulting in high potential for canopy fire carry. Saltcedar stands are often characterized by dense understory and soil surface litter layers comprised of additional fine fuels consisting primarily of annual grasses, for example, Japanese brome (*Bromus japonicus* Thunb. ex Murr.), cheatgrass (*Bromus tectorum* L.]), and saltcedar leaf litter (Lair and Eberts 2002).

Background and Research Needs

Critical knowledge gaps exist regarding restoration of saltcedar infestations, for which limited research or field experience exists, especially on aridic/xeric sites. Specifically, primary information needs include strategies and techniques for vegetative recovery in aridic, mature, monotypic saltcedar stands with no (desirable) understory and sites where potential is limited for natural or artificial recovery of willow and/or cottonwood species because of unavailability of supplemental water (via seasonal flooding, shallow water table, or irrigation). Best management practices are needed that integrate multiple management tools and are capable of addressing both localized (small scale) and landscape-scale, mesic and xeric saltcedar infestations. These practices should result in implementation of control and revegetation measures that provide rapid initial reduction of saltcedar; maintenance of control over extended time periods; and establishment of desirable vegetation that is ecologically (successionally) sustainable, competitive, resilient to further disturbance, and that provides multiple habitat, site stability, and forage benefits.

Vegetative restoration of sites impacted by invasion (and subsequent control) of saltcedar presents technical and conceptual challenges, particularly within the context of biological, fire, or foliar herbicide control. For example, research funded through the Cooperative State Research, Extension and Education Service and Initiative for Future Agriculture and Farming Systems addresses biological control of saltcedar (using *Diorhabda elongata* Brulle) as an economically sound alternative to other measures, especially in relation to reducing physical site disturbance and use of herbicides. The research places priority on evaluation of revegetation techniques in relation to anticipated results of biological control alone (that is, as the initial or primary treatment, leaving high densities and biomass of defoliated or standing dead material), as opposed to follow-up, maintenance control subsequent to mechanical, fire, or herbicidal measures.

Reducing the time for establishment of desired levels of cover, diversity, production, and habitat values is also important (Pinkney 1992; Anderson 1995; Lair and Wynn 2002). Natural recovery of saltcedar infestation sites following control measures, especially in less dense stands, needs to be evaluated in light of the definition of "recovery" and an acceptable time frame for it to occur. Natural recovery scenarios (that is, not artificially revegetated) often require 10 years or more for establishment of desirable, native vegetation, with the first 1 to 5 years typically dominated by ruderal weedy species. A prime objective should be to shorten or circumvent an extended ruderal and/or bare period by establishing diverse habitat characterized by predominance of early-, mid-, and late-seral perennial species. This also minimizes potential for capillary rise and salt accumulation at the soil surface following saltcedar reduction, and maintains lower wildfire hazard. Some sites may need initial establishment of earlier seral or transitional "ecobridge" species in order to cope with and adapt to harsh environmental conditions until the site stabilizes (from the standpoints of organic matter recovery, energy flow, and nutrient cycling). Other sites may facilitate later seral species and accelerated successional strategies.

Development and application of revegetation strategies also need to parallel recent technological developments in herbicidal and biological control of saltcedar, which hold great potential for rapid control of saltcedar on landscape scales. Valuable information can be derived from studies involving control of saltcedar by biological agents, fire, or herbicide application, especially in terms of the effect of growth medium manipulation (physically, biologically, chemically) on moisture capture and retention, restoration of a functional microbial community, species adaptation, and other management inputs. Amount and density of standing biomass (live and dead) remaining after control, seedbed preparation strategies, and time frame to achieve levels of control sufficient to favor vegetation establishment and site protection/stabilization are problematic in dense, mature saltcedar stands.

Effective techniques for seedbed preparation and seeding/outplanting in standing dead or defoliated material are needed that are more cost effective, require smaller equipment with less energy expenditure, and cause less environmental disturbance than conventional methods (for example, root plowing and raking). Presence of dense standing dead or defoliated saltcedar biomass poses limitations in relation to seeding techniques, seed interception in aerial applications, and shading impacts. After natural or prescribed fire treatment, undisturbed soil surfaces impacted by saltcedar leaf litter accumulation, salinity, hummocky microrelief, nitrogen limitations, and possible livestock trampling compaction may also restrict potential for successful revegetation. Absence of arbuscular mycorrhizae specifically symbiotic to native revegetation species (especially grasses and shrubs), because of the long duration of saltcedar occupation in dense, mature stands, may also be a significant constraint.

Saltcedar reduction may yield an interaction of both positive and negative impacts resulting from biological, fire, or herbicide application, requiring site-specific evaluation for restoration potential. Soil surface manipulation in the types and intensities needed for adequate soil surface manipulation (seedbed preparation) is absent following fire, biocontrol measures, and most herbicide applications (Szaro 1989; Pinkney 1992). Brief review to date of saltcedar revegetation literature, and communication with researchers and land managers experienced in saltcedar control and site restoration on xeric sites with dense, mature, monotypic infestations indicate that revegetation is difficult in the absence of soil surface manipulation (that is, some form of seedbed preparation) (Horton and others 1960; Lair and Wynn 2002). Different methods of achieving desirable growth medium conditions need testing through varied techniques of seedbed preparation to enhance microenvironmental conditions in the root zone of planted species, including saltcedar leaf litter dispersal or incorporation, improved contact of seeds with mineral soil, salinity reduction in surface soil layers, mycorrhizal fungi inoculation, and manipulation of soil nitrogen dynamics.

Stimulation of resprouting and increases in saltcedar density from remaining live root crowns and stems may occur as a result of saltcedar biomass reduction by mechanical measures or fire (wild or prescribed). The increased proportion of young, active growth increases competition for moisture, nutrients, and solar energy with planted vegetation. Use of mechanical methods or prescribed fire for biomass reduction needs sound planning and stringent controls as a viable tool, yielding an interaction of both positive and negative impacts. For example, rapid reduction of saltcedar canopy over large areas may be undesirable because of habitat sensitivity on sites occupied by endangered species such as the southwestern willow flycatcher (Busch 1995; Wiesenborn 1996). When applied on large (landscape) scales, reduction or elimination of biological control organism(s) may result, requiring reintroduction and subsequent redistribution (spread) over time of the biological agent(s) (Eberts 2002). Stimulation of resprouting from remaining live stems or root crowns resulting from mechanical or fire control measures, however, may promote higher rates of insect herbivory and increases in population size of biological agent(s) (Lair and Wynn 2002).

Current Research

Objectives

The USDI Bureau of Reclamation (USBR) is studying impacts of control measures (herbicidal, mechanical, and biological) and fire on site restoration/revegetation potential on aridic saltcedar infestation sites that are not candidates for revegetation with willow and cottonwood species. Development and evaluation of revegetation and habitat enhancement techniques are being conducted in historically dominant or monotypic saltcedar stands where potential for natural recovery of desirable native vegetation following control measures is limited or negligible. The studies address saltcedar control reflecting simulated biological control as the primary treatment (also applicable to foliar or basal bark herbicidal treatment) and mechanical control or fire where biological agents would be used as continuing maintenance (follow-up) control. The studies emphasize revegetation species response to mechanical techniques for saltcedar biomass reduction and seedbed preparation; manipulation of microbial (mycorrhizal) dynamics; and design and adaptation of selected species mixtures that are broadcast-applied (that is, simulation of aerial seeding), supported by companion single species trials.

Study Locations

Study sites for this research are San Marcial, New Mexico (approximately 30 mi [48 km] south of Socorro, New Mexico) and Cibola, Arizona (located approximately 45 mi [72 km] north of Yuma, Arizona).

San Marcial, NM—The San Marcial site is situated at an elevation of approximately 4,490 ft (1,369 m) on the immediate west side of the low flow conveyance channel along the Rio Grande River. Mean annual precipitation for the project area is 8.79 in (22.3 cm), with 5.47 in (13.9 cm) or 62 percent falling as rain during the summer monsoonal period of July through October (NOAA 2004). Soils of the project area are primarily fine sand and fine sandy loam, 0 to 2 percent mean slopes, typical of the braided channel floodplain zones adjacent to the middle Rio Grande River system (USDA NRCS 1988). All soils are moderately to strongly saline (electrical conductivity [EC_e] 7 to 25 mmhos/cm), and may have clay loam to clay subsoil horizons with depths to bedrock typically exceeding 60 in (152 cm). The site is now instrumented for collection of localized climate and soil environment data, utilizing a HOBO™ remote weather station (Onset Computer Corporation, Pocasset, MA)

The general study site represents two distinct age classes of monotypic saltcedar (*Tamarix ramosissima* Ledeb.) infestation (no shrub understory and negligible herbaceous understory). Younger (aboveground) saltcedar are characterized by mean stem diameters less than 3 in (7.6 cm) and mean canopy cover less than 80 percent, resulting from prior prescribed burning conducted by the BLM in 1994. Older stands of saltcedar were protected from fire by means of a firebreak installed in 1993, and consisted of dense, old-growth populations characterized by mean stem diameters equal to or greater than 3 in (7.6 cm) (maximum diameters up to 16 in [40.6 cm]), and mean canopy cover approaching

100 percent. Lack of historical record or onsite evidence of natural or artificial reduction of saltcedar biomass in this latter population suggests an undisturbed stand age of at least 40 years.

Cibola, AZ—The Cibola site is located at an elevation of approximately 230 feet (70 m) in the Cibola Valley along the immediate east side of the Colorado River. Mean annual precipitation for the general project area is 3.83 in (9.73 cm) (NOAA 2004). Bimodal peaks in mean monthly precipitation occur in August through September and December through February, with all precipitation occurring as rainfall. Soils of the project area are primarily deep, well-drained silt loams (USDA NRCS 1980) common to flood plain and alluvial sites (0 to 1 percent mean slopes) along this portion of the lower Colorado River. Soils are strongly saline, with salinity levels (as indicated by EC_e measurements) extremely high (40 to 90 mmhos/cm) in the surface layer (top 6 in [15 cm]), and low to moderate at 12-in (30-cm) soil depths (5 to 12.5 mmhos/cm).

The Cibola study site is comprised of mixed saltcedar and quailbush [*Atriplex lentiformis* (Torr.) S. Wats. ssp. *breweri* (S. Wats.) Hall & Clements] that was burned by wildfire on April 17, 2001. Saltcedar plants within the burn area are characterized by mean live stem diameters less than 2 in (5 cm) and mean, postfire canopy cover less than 25 percent.

Experimental Design and Statistical Analysis

Studies are replicated (4 blocks), split plot or split-split plot factorial designs suitable for ANOVA and multivariate analyses. These experimental designs incorporate evaluation of important response variables simultaneously within the same spatial and temporal context under a common error term. Univariate analysis was used to evaluate individual species responses, while multivariate techniques (for example, discriminant analysis, canonical correlation, multiple linear regression) assess treatment responses using combinations of plant community, climate, soil, and applied treatment variables. Studies incorporate control plots to reflect natural revegetation potential in the absence of treatment at all plot levels and within all replicates.

Seedbed Preparation, Mycorrhizal Inoculation, Seeding Mixture—Seedbed preparation (main plot) includes: 1) herbicide treatment only; 2) herbicide/shred/roller chop; 3) shred/roller chop; and 4) shred/roller chop/imprint.

Mycorrhizal inoculation (second level) includes: 1) broadcast granular; 2) pelleted seed coating; and 3) no treatment.

Seed mixtures (third level) include one of three grass/forb/shrub mixtures or no mixture, a “natural” recovery.

Treatments emphasize seeding without supplemental moisture (for example, seasonal flooding or irrigation) to reflect lower cost/lower maintenance vegetation establishment protocols and methodology. Specifically, treatments emphasize: 1) revegetation species response to mechanical techniques for saltcedar biomass reduction, seedbed preparation, and moisture capture/retention; 2) manipulation of microbial (mycorrhizal) regimes; and 3) design and adaptation of selected species mixtures that are broadcast-applied (that is, simulation of aerial seeding).

Project Term—Total project life is proposed for 5 years (2002 to 2006), involving baseline inventories, treatment applications, and posttreatment monitoring and weed management. Further, limited monitoring may continue for an additional 5 years following project completion, subject to research results, staff availability, and project funding. The intensive field data collection portion of the project is proposed for 3 years duration.

Baseline Inventories and Posttreatment Monitoring—Baseline and posttreatment inventories include soils (systematic core and electronic surface sampling), vegetation (fixed transects, using line intercept, line point, and systematic 1.0 m^2 [10.8 ft^2] quadrat sampling), and groundwater (monitoring wells). Posttreatment monitoring is conducted (at a minimum) once per year in late fall to early winter (October to December). Initial, measured field variables proposed for use in conducting baseline inventories and to evaluate treatment responses include soils, groundwater, vegetation, and wildlife management.

Using core sampling and surface electromagnetic techniques, soils are systematically sampled on an individual plot basis for surface (0 to 12 in [0 to 30 cm] and subsoil (12 to 36 in [30 to 90 cm]) texture, organic matter, fertility (macro- and micronutrients in the surface layer only), salinity (EC/SAR in the surface and subsoil), reaction (pH in the surface and subsoil), and moisture content/availability (surface and subsoil).

A minimum of one 2-in (5-cm) diameter, PVC-encased monitoring well per study was installed simultaneous with baseline inventories and prior to treatment applications for groundwater monitoring of ground water depth (baseline, pretreatment and monthly, posttreatment), conductivity, pH, alkalinity, major ions (Cl^-, $SO4^=$, Ca^{++}, Mg^{++}, Na^+, K^+), trace elements/metals, and NO_3^-/NO_2^-.

Vegetation monitoring included age class (baseline only), plant height, plant spacing, stem densities and diameters for saltcedar; species frequency; Vigor Index (function of culm and leaf height, seedhead production, and biomass); basal and canopy cover (total and by species) for both seeded and nonseeded; bare ground and litter; species diversity (Shannon-Weiner or modified Simpson’s); and biomass (live standing crop + standing dead; total and by species) for both seeded and nonseeded species.

Modified Habitat Suitability Index evaluations for wildlife monitoring will be conducted on resultant small plot plant communities, with extrapolations to potential landscape-scale communities of the same character, to estimate general habitat values based on desired plant community composition and revegetation results.

Herbicide Application—Saltcedar was herbicidally treated at San Marcial to simulate injury and defoliation from biocontrol insects, using backpack applications of triclopyr in vegetable oil as a basal bark treatment (25 percent v/v). Seeded species competition for moisture and nutrients, and adjustment to altered soil microbial and organic matter regimes in affected *Tamarix* communities, should be evaluated in the presence of live saltcedar root growth while undergoing aboveground defoliation over time (chronic stress leading to root reserve depletion). Ongoing control of saltcedar sprouts following fire (Cibola) or mechanical treatment (both studies) is maintained herbicidally on treated plots over the duration of the study via spot treatment using backpack sprayers, or as situations indicate following revegetation treatments, carpet roller, or rope wick application (dependent upon plant densities, prevalence of nontarget vegetation, and cost effectiveness). Secondary invasive species will be similarly controlled using labeled herbicides appropriate for the target species and land use type.

Mechanical Treatments—Mechanical treatments were used for saltcedar biomass reduction, seedbed preparation and mulching, salinity remediation, placement of seeds, and incorporation of soil microbial (mycorrhizal) amendments. These measures include saltcedar shredding/mulching by HydroAx™ with WoodGator™ attachment, roller-chopping and land imprinting. These measures are evaluated for efficacy in creating soil surface microrelief (microcatchments) to enhance precipitation capture and retention in the rhizosphere of seeded/planted vegetation; reduction, redistribution, and/or dilution of salts in the upper soil profile and saltcedar leaf litter on the soil surface; creating more spatially uniform soil texture characteristics (in both depth and lateral extent) for improved planted vegetation adaptation; and proper depth placement and incorporation of mycorrhizal inoculum.

Growth Medium Amendments—Mycorrhizal inoculum (using host-specific species, as determined from baseline soil samples, current research, and pertinent literature) was obtained either commercially (for example, RTI, Incorporated, Salinas, CA; Bionet LLC, Marina, CA), or was provided via Cooperative Research and Development Agreement (CRADA) as donated research materials from Bionet LLC. Inoculum was placed and incorporated into the prepared seedbed either as a preplant granular broadcast application using a manual, rotary fertilizer or seed spreader at a prescribed rate of 60 lb/ac (67 kg/ha) product or as raw inoculum incorporated in commercially pelletized seed coatings (CelPril, Incorporated, Manteca, CA; Seed Systems, Incorporated, Gilroy, CA) and applied during broadcast seeding using prescribed seeding rates. Regardless of source, the inoculum contained one or more species of mycorrhizae that are host-specific to the native revegetation plant species, including *Glomus intraradices, G. mosseae, G. aggregatum,* and/or *G. fasciculatus*.

Planting Methodology—Revegetation was conducted in combination with mechanical and mycorrhizal inoculation treatments. At San Marcial, seeds were broadcast using manual (hand-held) and/or mechanized (tractor PTO-driven) rotary spreader(s).

Several methods were used at Cibola, including broadcast using manual (hand-held) and/or mechanized (tractor PTO-driven) rotary spreader(s); broadcast using a mechanized Brillion-type seed drill; drilled using a research plot drill with leading deep-furrow openers; and seedlings outplanted manually or mechanically depending upon species, container type, soil conditions, and equipment availability. Planting was done in conjunction with selected mechanical seedbed preparation treatments using the roller chopper and/or imprinter to facilitate desired seed depth placement and juxtaposition of seeds to incorporated mycorrhizal inoculum (subject to the experimental design).

Species Selection—Emphasis is placed on testing native species (in conjunction with associated seeding/planting methodology) as single species, seed mixtures, and seedling transplants that best reflect environmental site adaptation, practical field applications by agencies and private landowners, commercial availability, and cost-effectiveness. Evaluation of competition between species within designed mixtures under saltcedar control conditions is also performed. Evaluations are made on individual species as well as resultant plant communities. General design and number of mixture applications are amenable to site specific adjustment at other southwestern sites subject to individual site attributes.

Mixtures of native shrubs, forbs and grasses (tables 1 and 2) were seeded or planted following various experimental combinations of herbicide and/or mechanical treatments (San Marcial: 16 species, July 15 to 17, 2002; Cibola: 23 species, January 30 to 31, 2003). The Cibola study also incorporates a demonstration of irrigated and nonirrigated, single species trials, utilizing seeds and seedlings.

Seed coating for mycorrhizal inoculation was performed in cooperation with Bionet LLC (Marina, CA) and CelPril, Incorporated (Manteca, CA) at the San Marcial site and Reforestation Technologies, Incorporated (Salinas, CA) and Seed Systems, Incorporated, (Gilroy, CA) at the Cibola site.

All species, singly or in mixtures, were selected for optimum adaptation to interactions of climate, soil, salinity, competition from existing vegetation, and planned treatments, including preconditioning treatments as needed (for example, stratification and/or scarification for seeds; selection for salinity tolerance and mycorrhizal inoculation potential for seedlings). Both studies incorporate "transitional" or "ecobridging" species concepts within mixtures, using regional natives that exhibit greater establishment potential in terms of germination, seedling vigor, and reproductive capability under the harsh climatic and soil conditions on saltcedar revegetation sites.

Native revegetation species were obtained through cooperation with the USDA Natural Resources Conservation Service (NRCS) Plant Materials Centers plus acquisition of local native harvest or commercial source material, depending upon individual species availability. Species were of local (endemic) or regional origin where possible. Final species and cultivar selection, for both mixture and single species applications, were determined in consultation with local/regional cooperators (for example, USDI Bureau of Land Management, USDI Fish and Wildlife Service, USDA Forest Service, State fish and game departments, NRCS, local environmental organizations, and USBR).

Results and Discussion

Selected San Marcial results only are presented for the sake of brevity and to demonstrate the potential for the applied treatments. First-, second-, and third-year data collection (2002 to 2004) addressed frequency and density variables only. Subsequent monitoring years include canopy cover, biomass (live standing crop), plant diversity, and vigor parameters.

Treatment response indicates promising emergence, establishment, and vigor of seeded quailbush, four-wing saltbush

Table 1—Mixtures and seeding rates for San Marcial, NM, saltcedar revegetation study.

Scientific Name	Common Name	Culivar or Pre-Release	Mixture Rate	PLS Mix Drilled [a]	PLS Mix Broadcast [a]
			PLS rate (seeds/ft^2):		20
			(%)	(lb/ac)[b]	(lb/ac)[b]
MIXTURE 1 - AGGRESSIVE					
Bouteloua curtipendula	Sideoats grama	Niner	10.0	0.50	1.01
Elymus elymoides	Bottlebrush squirreltail		10.0	0.55	1.09
Elymus trachycaulus	Slender wheatgrass	Pryor	10.0	0.68	1.35
Panicum virgatum	Switchgrass	Blackwell	15.0	0.43	0.87
Pascopyrum smithii	Western wheatgrass	Arriba	10.0	0.87	1.74
Sporobolus giganteus	Giant dropseed		5.0	0.03	0.06
Sporobolus wrightii	Giant sacaton		5.0	0.03	0.05
Plantago insularis	Wooly plaintain		2.0	0.06	0.13
Sphaeralcea coccinea	Scarlet globemallow		3.0	0.06	0.13
Heliotropium curassavicum	Quailplant; salt heliotrope		2.0	0.03	0.05
Atriplex canescens	Fourwing saltbush		12.7	2.55	5.11
Forestiera neomexicana	New Mexico olive	Jemez	0.30	0.07	0.15
Atriplex lentiformis	Quailbush		10.0	0.21	0.42
Shepherdia argentea	Silver buffaloberry		5.0	1.16	2.32
		TOTALS =	100.0	7.24	14.48
MIXTURE 3 - SANDY					
Achnatherum hymenoides	Indian ricegrass	Paloma	10.0	0.57	1.14
Elymus elymoides	Bottlebrush squirreltail		10.0	0.55	1.09
Elymus lanceolatus lanceolatus	Thickspike wheatgrass	Critana	5.0	0.34	0.68
Eragrostis trichodes	Sand lovegrass	Bend	5.0	0.03	0.07
Leptochloa dubia	Green sprangletop		5.0	0.10	0.19
Panicum virgatum	Switchgrass	Blackwell	15.0	0.43	0.87
Pleuraphis (Hilaria) mutica	Tobosagrass		10.0	0.23	0.46
Schizachyrium scoparium	Little bluestem	Pastura	10.0	0.42	0.85
Sporobolus cryptandrus	Sand dropseed		5.0	0.01	0.02
Oenothera deltoides	Dune evening primrose		2.0	0.06	0.13
Plantago insularis	Wooly plaintain		5.0	0.16	0.32
Sphaeralcea coccinea	Scarlet globemallow		5.0	0.10	0.21
Atriplex polycarpa	Desert saltbush		3.0	0.04	0.08
Lycium torreyi / L. andersonii	Torrey / Anderson's wolfberry		4.0	0.07	0.14
Ephedra viridis	Green ephedra		4.0	2.06	4.12
Ephedra nevadensis	Nevada ephedra		2.0	1.03	2.06
		TOTALS =	100.0	6.22	12.43

Scientific Name	Common Name	Culivar or Pre-Release	Mixture Rate	PLS Mix Drilled [1]	PLS Mix Broadcast [1]
			PLS rate (seeds/ft^2):		20
			(%)	(lb/ac)[2]	(lb/ac)[2]
MIXTURE 2 - MESIC					
Bothriochloa barbinodis	Cane bluestem	Grant	15.0	0.21	0.42
Elymus canadensis	Canada wildrye		9.0	0.83	1.65
Elymus lanceolatus	Streambank wheatgrass	Sodar	5.0	0.32	0.64
Pascopyrum smithii	Western wheatgrass	Arriba	15.0	1.31	2.62
Puccinellia airoides	Nuttall's alkaligrass		5.0	0.02	0.04
Sporobolus airoides	Alkali sacaton	Salado	16.0	0.10	0.21
Anemopsis californica	Yerba mansa		5.0	0.04	0.08
Sphaeralcea coccinea	Scarlet globemallow		5.0	0.10	0.21
Baccharis glutinosa	Seep willow		5.0	0.00	0.01
Lycium andersonii	Anderson's wolfberry		6.0	0.11	0.21
Chilopsis linearis	Desert willow		5.0	0.70	1.39
Chrysothamnus nauseosus graveolens	Rubber rabbitbrush		4.0	0.08	0.17
Sarcobatus vermiculatus	Greasewood		5.0	0.20	0.41
		TOTALS =	100.0	4.03	8.06
STANDARD MIXTURE					
Bouteloua curtipendula	Sideoats grama	Niner	10.0	0.50	1.01
Elymus trachycaulus	Slender wheatgrass	Pryor	11.0	0.74	1.49
Panicum virgatum	Switchgrass	Blackwell	15.0	0.43	0.87
Pascopyrum smithii	Western wheatgrass	Arriba	10.0	0.87	1.74
Sporobolus airoides	Alkali sacaton	Salado	15.0	0.12	0.23
Sporobolus giganteus	Giant dropseed		5.0	0.03	0.05
Anemopsis californica	Yerba mansa		2.0	0.02	0.03
Plantago insularis	Wooly plaintain		2.0	0.06	0.13
Sphaeralcea coccinea	Scarlet globemallow		2.0	0.04	0.08
Atriplex canescens	Fourwing saltbush		12.0	2.41	4.83
Baccharis glutinosa	Seep willow		3.0	0.00	0.00
Atriplex lentiformis	Quailbrush		4.0	0.08	0.17
Lycium andersonii	Anderson's wolfberry		7.0	0.12	0.25
Chrysothamnus nauseosus graveolens	Rubber rabbitbrush		2.0	0.04	0.08
		TOTALS =	100.0	5.48	10.96

[a] Seeding rates derived from desired number of PLS seeds/ft^2 (1 seed/ft^2 = 11 seeds/m^2) using mean of available literature values for number of seeds/lb (source: Hassell and others 1996).
[b] 1 lb/ac = 1.1 kg/ha.

Table 2—Mixtures and seeding rates for Cibola, AZ, saltcedar revegetation study.

Scientific Name	Common Name	Culivar or Pre-Release	Mixture Rate (%)	PLS Mix Drilled [a] (lb/ac)[b]	PLS Mix Broadcast [a] (lb/ac)[b]
			PLS rate (seeds/ft^2):		30
MIXTURE 1 - "MESIC"					
Distichlis spicata	Inland saltgrass		10.0	0.30	0.60
Pleuraphis (Hilaria) rigida	Big galleta		5.0	0.22	0.45
Bouteloua rothrockii	Rothrock grama		5.0	0.03	0.07
Sporobolus airoides	Alkali sacaton	Salado	15.0	0.15	0.29
Camissonia brevipes	Golden evening primrose		3.0	0.03	0.07
Cassia covesii	Desert senna		3.0	0.43	0.86
Baileya multiradiata	Desert marigold		4.0	0.06	0.12
Acacia gregii	Catclaw acacia		5.0	31.36	62.73
Atriplex lentiformis	Quailbush		20.0	0.63	1.25
Ambrosia dumosa	White bursage		5.0	0.92	1.84
Chilopsis linearis	Desert willow		5.0	1.05	2.09
Lycium andersonii	Anderson wolfberry		5.0	0.13	0.26
Prosopis pubescens	Tornillo; screwbean mesquite		10.0	11.62	23.23
		TOTALS =	100.0	**46.93**	**93.87**
MIXTURE 2 - "ARID"					
Bouteloua rothrockii	Rothrock grama		5.0	0.03	0.07
Pleuraphis (Hilaria) rigida	Big galleta		10.0	0.45	0.90
Pleuraphis (Hilaria) jamesii	Galletagrass	Viva	5.0	0.49	0.99
Sporobolus wrightii	Giant sacaton		10.0	0.08	0.16
Baileya multiradiata	Desert marigold		5.0	0.07	0.15
Haplopappus acradenius	Alkali goldenbush		5.0	0.10	0.20
Sphaeralcea ambigua	Desert globemallow		5.0	0.16	0.31
Atriplex canescens	Fourwing saltbush		10.0	3.02	6.03
Atriplex polycarpa	Desert (littleleaf) saltbush		5.0	0.10	0.20
Atriplex lentiformis	Quailbush		20.0	0.63	1.25
Allenrolfia occidentalis	Iodinebush; pickleweed		5.0	0.02	0.03
Lycium exsertum	Desert wolfberry		5.0	0.16	0.31
Prosopis glandulosa torreyana	Honey mesquite		10.0	11.62	23.23
		TOTALS =	100.0	**16.92**	**33.83**

[a] Seeding rates derived from desired number of PLS seeds/ft^2 (1 seed/ft^2 = 11 seeds/m^2) using mean of available literature values for number of seeds/lb (source: Hassell and others 1996).
[b] 1 lb/ac = 1.1 kg/ha.

[*Atriplex canescens* (Pursh) Nutt.], and slender wheatgrass [*Elymus trachycaulus* (Link) Gould ex Shinners]. Alkali sacaton [*Sporobolus airoides* (Torr.) Torr.], sideoats grama [*Bouteloua curtipendula* (Michx.) Torr.], Anderson wolfberry (*Lycium andersonii* Gray), and giant dropseed (*Sporobolus giganteus* Nash) are also establishing in lesser quantities. Minor occurrences of native species exhibiting natural recovery (nonseeded) following saltcedar reduction include vine mesquite (*Panicum obtusum Kunth*), salt heliotrope (*Heliotropium curassavicum* L.), buffalo gourd (*Cucurbita foetidissima* Kunth), and jimson weed (*Datura stramonium* L.).

Initial frequency and density of seeded plant materials were highest in plots treated with herbicide only (no mechanical treatment), achieving frequencies of 16 to 47 percent and densities of 0.25 to 3.0 plants/m^2 (0.023 to 0.28 plants/ft^2) (figures 1 and 2). However, all plants in the herbicide-only plots were extremely stunted (less than 5 cm (2 in) in height), weak, and highly stressed. The saltcedar stands were 75 percent defoliated from the herbicide treatment. The remaining canopy of dense saltcedar, however, still provided ample cover such that shading and protection from wind maintained higher humidity levels than those in plots where mechanical biomass reduction had occurred. It is hypothesized that this shading and higher humidity promoted greater initial germination of seeded materials. However, as the growing season progressed, factors of continued shading, high salinity in exposed (bare) surface soil, and undisturbed, highly saline saltcedar leaf litter duff severely inhibited growth following germination.

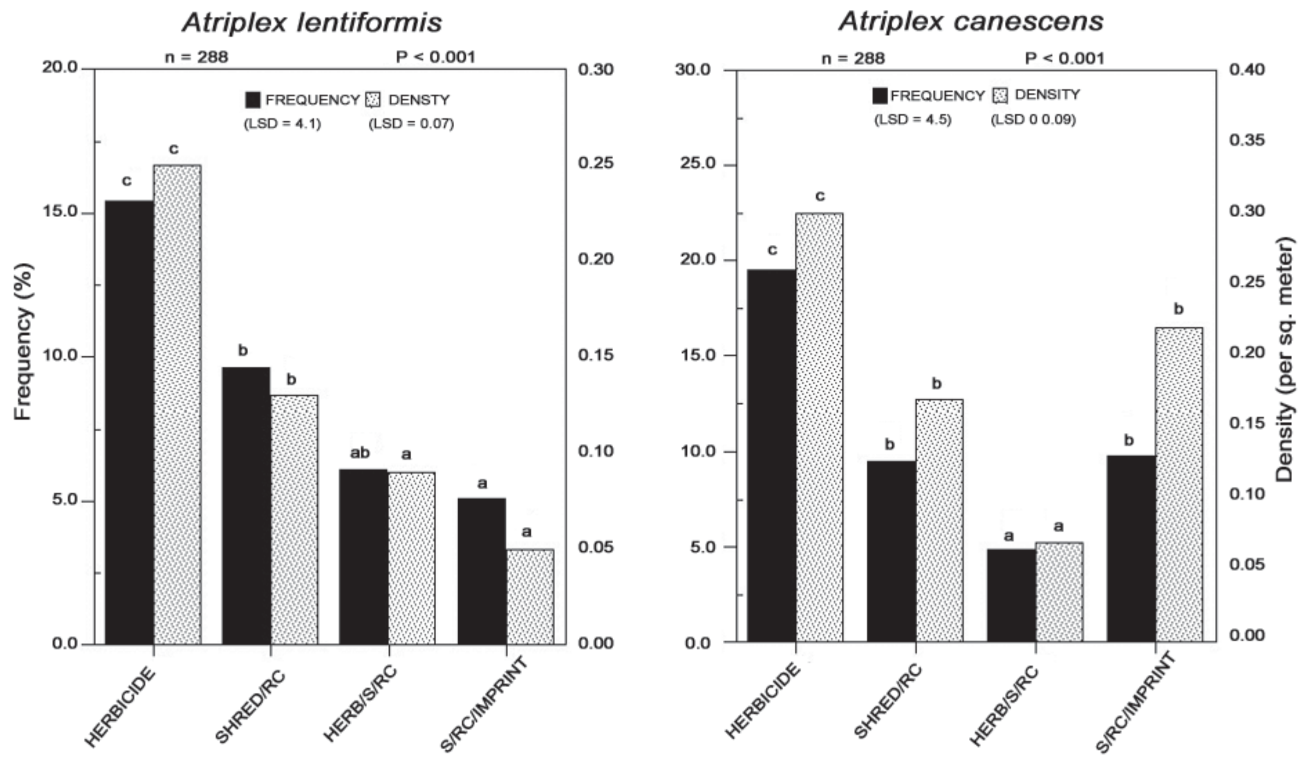

Figure 1—Response to herbicidal and mechanical treatment by *Atriplex lentiformis* and *A. canescens*. First year (2002) data for San Marcial, NM, saltcedar revegetation study. Dark bars are frequency (left Y-axis); light bars are density (right Y-axis). HERB = herbicide; SHRED or S = Woodgator shredded; RC = roller chopped. Bars within a parameter (of like color) with different letters are significantly different at $P < 0.001$.

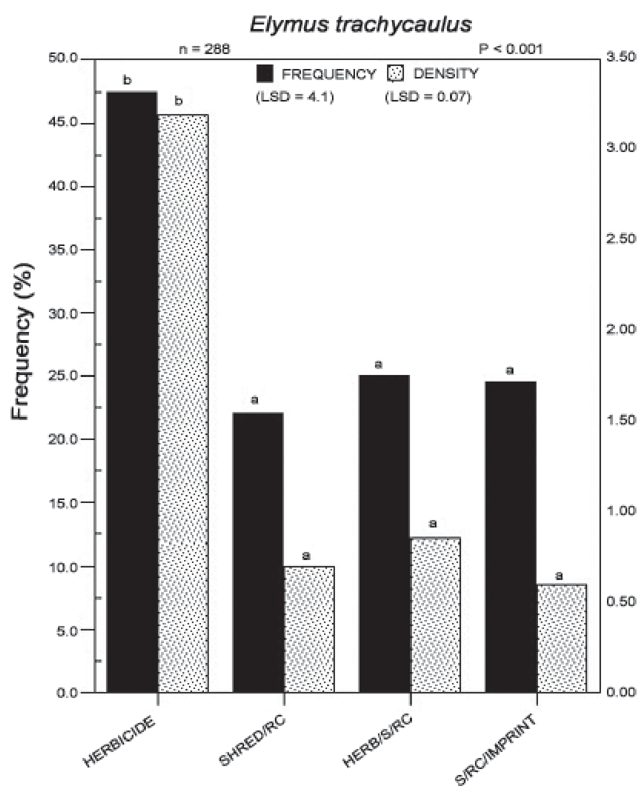

Figure 2—Response to herbicidal and mechanical treatment by *Elymus trachycaulus.* First year (2002) data for San Marcial, NM, saltcedar revegetation study. Dark bars are frequency (left Y-axis); light bars are density (right Y-axis). HERB = herbicide; SHRED or S = Woodgator shredded; RC = roller chopped. Bars within a parameter (of like color) with different letters are significantly different at $P < 0.001$.

While mechanically treated plots exhibited less initial germination and emergence of the seeded species (figures 1 and 2), frequency and density ranging from 5 to 25 percent and 0.05 to 0.8 plants/m^2 (0.005 to 0.007 plants/ft^2) respectively, indicate desirable emergence of several of the key seeded species in light of the severe site environmental constraints. Precipitation received at the site strongly reflected the southwestern regional drought status, with 7.69 in (19.5 cm; 87 percent of mean annual precipitation) and 5.89 in (15.0 cm; 67 percent of mean annual precipitation) received during the 2002 to 2003 initial establishment years, respectively. Of greater importance, essentially all of the emerged species exhibited greater productivity (high growth rates, vigor, and biomass production). Canopy heights ranged from 0.5 to 2.0 m (1.6 to 6.6 ft), 0.3 to 1.5 m (1.0 to 4.9 ft), and up to 45 cm (17.7 in) for quailbush, fourwing saltbush, and the two dominant grasses (slender wheatgrass, sideoats grama), respectively. Many of the plants were already sexually reproductive after one growing season, particularly sideoats grama.

Essentially 100 percent of the species that emerged under standing saltcedar (herbicide treatment only) in 2002 are dead and decomposed. In contrast, the dominant shrub species in mechanically treated plots have greatly increased in frequency and density, doubled in canopy height and volume, and most are sexually reproductive. It is anticipated that continued germination, emergence and establishment will occur in mechanically treated plots as seed dormancy mechanisms are broken and seedling recruitment from established plants increases. Increased germination and emergence for the dominant species may also be a function of the roller chopping treatments, which provide depressions for increased moisture capture and retention, and salinity reduction in the depression bottoms, providing microsites for enhanced seed germination.

Few differences were noted between mechanical treatments for saltcedar biomass reduction and seedbed preparation (figures 1 and 2), particularly for the seeded grasses. Herbicidal defoliation of saltcedar prior to mechanical shredding and mulching of the saltcedar, however, reduced frequency and density of the saltbushes (figure 1), perhaps suggesting potential adverse impacts on amount and/or characteristics (chip size, amount of fine stems, recalcitrance of larger stems) of the resultant mulch material. While the data suggest that there are negligible differences between mechanical treatments, all such treatments resulted in saltcedar mulch material uniformly covering the soil surface. With apparent greater establishment of seeded species on mulched areas than in standing (herbicidally treated) saltcedar, potentially positive aspects of in situ, saltcedar-derived mulch cover are evident. These potential benefits include weed suppression resulting from the following:

- Minimized soil disturbance (in comparison with traditional root plowing and root raking);
- Reduction of exposed bare soil;
- Increased soil C:N ratios, providing establishment advantage to later seral (nonruderal), perennial species;
- Moisture conservation;
- Moderation (buffering) of temperature and wind extremes;
- Salinity remediation through reduction of evaporation and capillary rise of salts to the soil surface;
- Microsite environment and protection for seedlings;
- Cost savings (in comparison with traditional root plowing and root raking);
- Younger (aboveground) stands of saltcedar (5 cm [2 in] mean stem diameter or less) amenable to biomass mulching by roller chopper alone.

Sideoats grama exhibited positive response to mycorrhizal inoculation (figure 3), with frequency and density values 2.5 to 4.5 times greater than under no inoculation. This finding suggests that mycorrhizal colonization and association with seeded native, mycorrhizal species can occur on highly saline/sodic sites characteristic of mature, monotypic saltcedar infestations. Given the high salinity (mean EC_e of 16 mmhos/cm) of the seeded soils, these findings also suggest that reintroduction of mycorrhizal populations into saltcedar infestation sites is more dependent on co-introduced presence of native host plant species than on soil salinity levels. This capability is critical in enabling and accelerating establishment of desirable, mycorrhizae-dependent native species on these sites. This is particularly important for more rapid establishment and spread of competitive, transitional ("eco-bridging") native

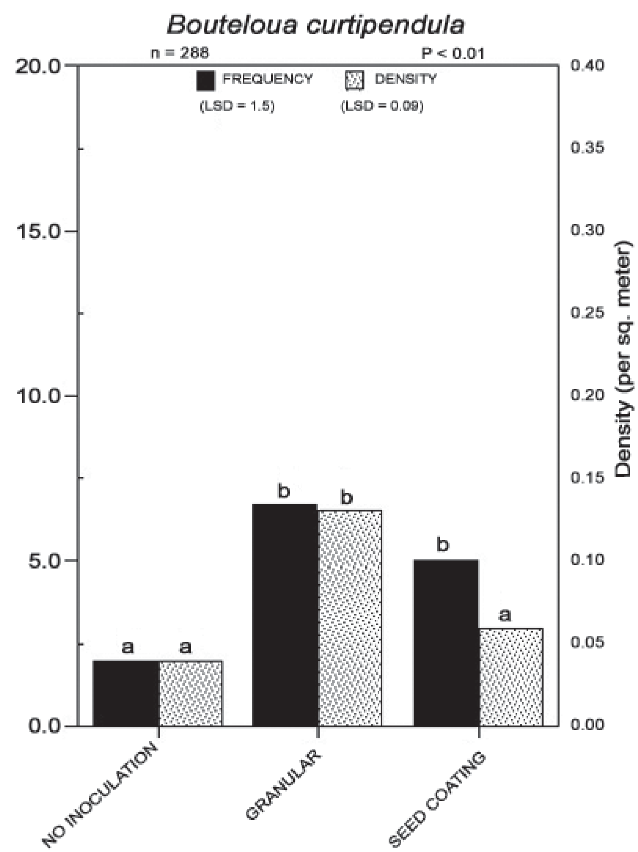

Figure 3—Response to mycorrhizal inoculation treatment by *Bouteloua curtipendula.* First year (2002) data for San Marcial, NM, saltcedar revegetation study. Dark bars are frequency (left Y-axis); light bars are density (right Y-axis). Bars within a parameter (of like color) with different letters are significantly different at $P < 0.01$.

species that help suppress encroachment of secondary invasive species following saltcedar control. The saltbushes and slender wheatgrass exhibited no positive response to mycorrhizal inoculation, consistent with the literature and the author's experience that these species are only mildly- to non-mycorrhizal, and thus are not dependent on mycorrhizal associations for initial establishment.

While there were no differences in sideoats grama frequency between mycorrhizal inoculation methods (figure 3), sideoats grama density (abundance) was reduced under seed coating inoculum incorporation. This result may be reflective of the seed coating process enclosing and binding mycorrhizal spore material more tightly to the immediate floret or seed coat envelope, rather than being distributed more uniformly through the potential rhizosphere of the germinating and growing plant. This latter state is considered more desirable than mycorrhizal inoculum material being more tightly bound to the seed during early growth and establishment (St. John 2003). Trends for inoculation efficacy will continue to be monitored in subsequent years.

There was poor correlation ($r^2 < 0.10$) of dominant seeded species frequency or density with soil salinity/sodicity across plots and treatments. At the San Marcial site, soil EC_e ranged from 7 to 25 mmhos/cm. The majority of the dominant seeded species that have emerged are highly saline tolerant (by design), and thus may minimize any correlation to soil salinity because of their high tolerance levels.

Summary

Formulation of revegetation strategies that provide site stabilization, resistance to further saltcedar and secondary weed infestation, and acceptable habitat values for affected wildlife species becomes particularly problematic in monotypic saltcedar stands under biological, fire, and herbicidal (that is, nonmechanical) control scenarios. Amount and density of standing biomass (live and dead) remaining after control poses limitations in relation to seeding and planting techniques, seed interception in aerial (broadcast) applications, and seedbed preparation methods. Undisturbed soil surfaces impacted by saltcedar leaf litter accumulation, salinity, hummocky microrelief, and nutrient limitations restrict potential for successful revegetation. Long duration of saltcedar occupation may deplete needed microbial communities, particularly arbuscular mycorrhizae symbiotic and host-specific to native revegetation species.

Sixteen species of native shrubs, forbs, and grasses were seeded following various experimental combinations of simulated biocontrol treatment. Establishment results from the San Marcial study site indicate promising emergence, establishment and vigor of seeded quailbush, four-wing saltbush, and slender wheatgrass, alkali sacaton, sideoats grama, Anderson wolfberry, and giant dropseed.

While few differences were noted between mechanical treatments for saltcedar biomass reduction and seedbed preparation, these treatments resulted in saltcedar mulch material uniformly covering the soil surface. Positive aspects of in situ, saltcedar-derived mulch cover include weed suppression, moisture conservation, moderation (buffering) of temperature and wind extremes, salinity remediation through reduction of evaporation and capillary rise of salts to the soil surface, microsite environment and protection for seedlings, cost savings, and younger (aboveground) stands of saltcedar following control that are amenable to biomass mulching by roller chopper alone.

Sideoats grama (a mycorrhizal "indicator" species) exhibited positive response to mycorrhizal inoculation, suggesting that mycorrhizal colonization and association with seeded native species can occur on highly saline/sodic sites characteristic of mature, monotypic saltcedar infestations. This finding also suggests that absence (depletion) of desirable mycorrhizal populations in mature saltcedar stands is a function of native species displacement and loss (native host-dependent) rather than a direct response to increasing soil salinity/sodicity.

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Meadow Restoration in the Sawtooth National Recreation Area in Southern Idaho

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Abstract: High elevation sites are ecologically fragile. When disturbed, these sites can take a long time to recover. However, native plant seeds are often unavailable and little is known about growing many of these plant species. This paper describes the cooperative restoration of a high elevation meadow in the Sawtooth National Recreation Area after a severe disturbance. The methods are presented for others who may be faced with a similar situation or working with the same native plant species.

Keywords: native plants, grasses, forbs, shrubs, restoration, seed collection, seed cleaning, plant propagation, site disturbance, container stock

Introduction

Many land managers are faced with a need to restore wildlands to their original ecological state following disturbance. Disturbances may be due to fire, livestock or wildlife grazing, timber harvest, recreation, extreme weather events, or other site injuries that changed or took away the natural vegetation on the site. The resulting restoration needs may cover as little as an acre or less, or as large an area as a landscape. One of the foremost challenges in beginning a restoration project is finding seeds of the correct native species, adapted to the local area, and for the appropriate location and elevation of the site. It is possible that little information is known about the desired native plant species, seed treatments, germination, culture, and production.

This paper will describe a project to restore a fragile high elevation meadow in the mountains of southern Idaho. The project was a cooperative effort between USDA Forest Service Sawtooth National Recreation Area (SNRA), USDA Forest Service Rocky Mountain Research Station (RMRS), and USDA Forest Service Lucky Peak Nursery (LPN). The purpose of the paper is to provide a stepping stone for others to build and improve upon.

The Problem

The Site

The site of focus is located south of Stanley, Idaho in the White Cloud Mountains. It is a small mountain meadow, about 1 ac (0.4 ha) in size, surrounded by lodgepole pine (*Pinus contorta*) forests, and very near Fourth of July Creek. At 9,000 ft (2,740 m), the meadow is an ecologically fragile home to many species of forbs, grasses, sedges, and a few shrubs. The soil is a well-drained loamy sand derived from the granitic bedrock of the Idaho Batholith. The water table is high in the spring but falls rapidly in early summer. The site is fragile because the short summer growing season is further limited by cool temperatures and summer drought. Plants have a limited opportunity to establish and grow in this environment, which can be very harsh 10 to 11 months of the year.

The site is important for many reasons. The Sawtooth National Recreation Area is famous for its pristine beauty. People come from across the U.S. and around the world to hike, camp, bike, fish, watch wildlife, drive motorized vehicles on and off roads, view the scenery, as well as many other types of recreation. Much of this roadless area will soon be designated wilderness. The site is beside a road less than 0.5 mi (0.8 km) from a popular trailhead. With little or no vegetative cover, the meadow is at risk to invasion by noxious weeds and spreading those species to surrounding areas and the pristine roadless area. Erosion is an additional hazard, with no vegetative cover and roots to bind the soil. The proximity to Fourth of July Creek could lead to sedimentation in the stream.

The Disturbance

In spring 2002, while the meadow was in a wet, muddy condition, a group of young people drove 4-wheel-drive vehicles around the meadow, destroying the existing vegetation and creating deep ruts. The participants were fined afterwards, but the damage was already done (figure 1).

Results: The Solution

Site Preparation

In order to remove the ruts from the meadow, reduce the potential for erosion, and make the meadow more presentable to the public, SNRA district personnel brought in a small tractor with a tiller and smoothed the surface after it dried out. Little vegetation grew on the site that summer.

Seed Collection

During the first week in August, people from the SNRA district and LPN visited the site and located some nearby areas where seed sources were available for revegetating the site. During the first week in September, we brought together a crew composed of a botanist from the SNRA, a person from LPN, and three people from the RMRS with experience in collecting native plant seeds. The crew, led by the botanist, spent 2 days collecting forb, grass, and shrub seeds in nearby meadows (figure 2).

Seeds were collected by hand-picking, or more often stripping, seeds into paper bags. The bags were labeled with time, date, species, and location. Seeds from 18 species were collected. More seeds were collected from abundant plants such as Idaho fescue (*Festuca idahoensis*) and small-winged sedge (*Carex microptera*). Lesser amounts of seeds were

Figure 1—Meadow after it was roughened by 4-wheel-drive vehicles. Notice the ruts in the mud and the lack of vegetation.

Figure 2—Collecting native seeds in a nearby meadow.

collected from species where the plants were not plentiful, seeds were not quite ripe, or plants were past the peak of seed production.

Seed Treatment

The seeds were taken to LPN and processed for sowing. Initially, seeds were spread out on racks until dry. The various kinds of seeds were cleaned using three machines: clipper, dewinger, and air separator. All lots were clean enough to sow in the greenhouse.

Information on seed treatment and stratification for each species was obtained from the Native Plant Network Web site (www.nativeplantnetwork.org). The seeds were placed in small cotton bags and soaked in a 3 percent solution of peroxide (H_2O_2) for 2 hours to kill any surface pathogens. After a thorough rinse, the seeds were soaked in gibberillic acid (GA_3) for 24 hours to improve germination. The bags of seeds were then drained and place in air tight plastic bags in a cooler at 34 °F (1 °C). This stratification process lasted 3 weeks or longer depending on the species.

Tables 1 through 3 present information on how the seeds of all species were treated before sowing in the greenhouse. The shaded rows in the tables indicate which species were eventually planted on the SNRA meadow. Because there was no mold or damping-off observed during stratification or in the greenhouse, the peroxide sanitation treatment seemed to be effective. Whether the gibberilic acid treatment had any effect is uncertain.

Sowing and Greenhouse Culture

Seeds were surface dried before sowing into 160/120 Styroblock™ containers (7.3 in^3 [120 cm^3], 9 in [22.8 cm] depth) filled with a 50:50 mixture of peat and vermiculite. The deeper than normal blocks were used to provide more rooting volume and a longer root system for outplanting. However, the plugs proved to be difficult to extract and harder to plant than standard length 160/90 Styroblock™ plugs (5.5 in^3 [90 cm^3], 6 in [15.2 cm] depth). Several seeds (3 to 5) were sown in each cell. No thinning was done. This was fine for the grasses, but the forbs and shrubs should have been thinned to one plant per cell to develop sturdier plants. The seeds were placed on the soil surface and, after the blocks were put in the greenhouse and watered well, a very thin white fabric was put over the top to protect the seeds and maintain a high humidity in the seed zone (figure 3). The fabric was 0.5 oz (14 g) white, spunbound fabric used in commercial grass seeding. It is called "Seed and Plant Guard," available through the DeWitt Company™ (Sikeston, MO). The weave is somewhat porous to allow irrigation over the top. After germination (2 weeks), the fabric was removed. Seeding took place in early January. By mid-May, plants were mature and were extracted at that time (figure 4).

Table 1—Seed treatments and germination success for grass species.

Species	Common name	Seed treatment			Germination[a]
		H_2O_2 soak (3%)	GA_3 soak	Cold strat	
Alopecurus spp.	Meadow foxtail	2 hours	24 hours	3 weeks @34 °F	Excellent
Carex microptera	Small-winged sedge	2 hours	24 hours	4 weeks @ 34 °F	Poor
Festuca idahoensis	Idaho fescue	2 hours	24 hours	3 weeks @ 34 °F	Good
Carex aenea	Bronze sedge	2 hours	24 hours	3 weeks @ 34 °F	Poor

[a]Poor = <6 percent cells; good = 6 to 90 percent; excellent = 90 percent +.

Table 2—Seed treatments and germination success for forb species.

Species	Common name	Seed treatment			Germination[a]
		H_2O_2 soak (3%)	GA_3 soak	Cold strat	
Antennaria microphylla	Everlasting pussytoes	2 hours	24 hours		Excellent
Aster conspicuous	Showy aster	2 hours	24 hours	3 weeks @34 °F	Excellent
Balsamorhiza sagittata	Arrowleaf balsamroot	2 hours	24 hours	4 weeks @34 °F	Poor
Castilleja spp.	Paintbrush	2 hours	24 hours	4 weeks @34 °F	Poor
Erogonum heracleoides	Buckwheat	2 hours	24 hours	3 weeks @34 °F	Good
Geranium viscosissinum	Wild geranium	2 hours		4 weeks @34 °F	Good
Hackelia spp.	Wild forget-me-not	2 hours	24 hours	4 weeks @34 °F	Poor
Penstemon ryberg	Penstemon	2 hours	24 hours	4 weeks @34 °F	Excellent
Potentilla gracilis	Cinquefoil	2 hours	24 hours	4 weeks @34 °F	Excellent
Senecio spp.	Western groundsel	2 hours	24 hours	4 weeks @34 °F	Excellent
Zigadenus elegans	Death camas	2 hours	24 hours	4 weeks @34 °F	Excellent

[a]Poor = <60 percent cells; good = 60 to 90 percent; excellent = 90 percent +

Table 3—Seed treatments and germination success for shrub species.

Species	Common name	Seed treatment			Germination[a]
		H_2O_2 soak (3%)	GA_3 soak	Cold strat	
Lupinus argenteus	Silvery lupine	24 hours in H_2O	Tumbled for 1 minute	None	Began to germinate too quickly
Potentilla fruticosa	Shrubby cinquefoil	2 hours in H_2O_2, 24 hours in GA_3	None	4 weeks @34 °F	Excellent

Seedlings were packed into plastic bags that were arranged upright in waxed boxes. They were stored in a cooler at 35 °F (1.6 °C) for 2 weeks. Success of germination is shown in the last column in tables 1 through 3. In general, poor germination was defined as less than 60 percent cells filled; good germination was 60 to 90 percent of cells filled; and excellent germination was 90 percent of cells filled. In total, about 4,000 plants, comprised of 15 species, were packed and outplanted.

Outplanting

Outplanting took place during the first week in June. It was a wet, snowy day on the planting site. Workers were USDA Forest Service employees who volunteered for the 1-day detail. Soil conditions were wet and the temperature was above freezing. The snowpack had melted off a few days before, but light rain and snow fell during much of the day.

Seedlings were transported in the back of a pickup covered by a tarp. The plastic bags of plants were distributed on the site by the SNRA botanist to match the right microsites to the species. Planters then came along with shovels and planting bars and put the plants in the ground.

The summer that followed was drier than normal. Most of the plants, however, were still alive in September (figure 5). Mortality was attributed to drought, shallow planting causing desiccation, and damage from pocket gophers.

Conclusion: The Consequences

The SNRA meadow restoration was only a small project. The amount of seeds, the number of plants produced, and the area revegetated were tiny in the big perspective. However, the success of this restoration project goes far beyond the borders of the SNRA meadow. For the SNRA, it has opened the possibility of restoring other sites that, for a long time, they have thought they would just have to live with. For Lucky Peak Nursery, it has been a spring board into a more

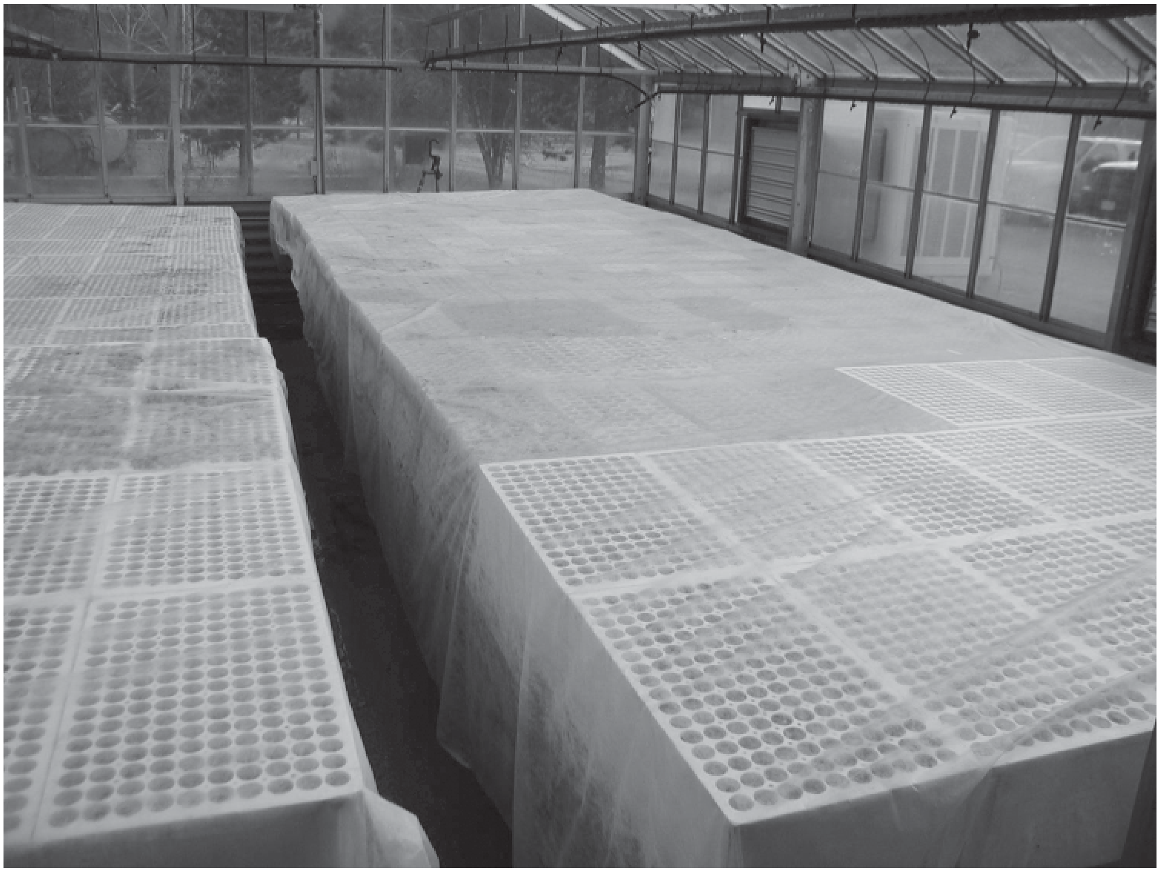

Figure 3—A light fabric called "Seed and Plant Guard" was place over the Styroblock™ containers to protect the seeds and maintain an environment to promote germination.

Figure 4—Some of the SNRA native plants in the greenhouse during April 2003. Idaho fescue and cinquefoil are in the background, meadow foxtail in the center, and pussy toes and shrubby cinquefoil in the foreground.

Figure 5—The mountain meadow in September of 2003 after one growing season following outplanting.

diversified plant business. It has led to other partnerships in the production of native plant stock and the production of native plant seeds in the nursery. Now with a new 24,000 ft^2 (2,230 m^2) greenhouse for plant production and a new small plot combine for harvesting seeds, LPN capabilities just keep growing. It has given other public land managers ideas about what they can achieve in restoration of high elevation meadows and other ecosystems all the way down to the dry valley floor.

It is not within the scope of this paper to speculate on the future. However, with the need for restoration of disturbed lands in the Intermountain West currently at millions of acres, and native seed stores minimal, the task facing land managers is huge. Through cooperation, we are chipping away at this daunting task and can someday gain momentum that will bring these lands back to their original useful condition.

Revegetation of Reconstructed Reaches of the Provo River, Heber Valley, Utah

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Abstract: In 1999, the Utah Reclamation Mitigation and Conservation Commission began the Provo River Restoration Project to create a more naturally functioning riverine ecosystem between Jordanelle Dam and Deer Creek Reservoir. The purpose of the project was to mitigate for past impacts to riverine, wetland, and riparian habitats caused by the Central Utah Project and other Federal reclamation projects in Utah. Project implementation followed a management model where a great deal of planning and study preceded construction, which was closely followed by monitoring. Lessons applied to habitat restoration include: avoiding compaction; working with the natural disturbance regime of the river; and choosing the right plants for the site, including selecting the right size plant materials and outplanting at the appropriate density. Lessons learned include coordinating plant installation with plant availability and planting site availability, and irrigating during drought.

Keywords: fish habitat, wildlife habitat, native species, ecosystem restoration, riparian restoration

Introduction

Prior to the 1950s, the middle Provo River in Utah offered outstanding fish and wildlife habitat. This was due in part to the Provo River freely meandering through the Heber Valley. These bends in the river provided deep holes for fish and a dense streamside forest for many species of birds. This productive habitat was altered in the 1940s and 1950s when the river was dammed, channelized, and forced between dikes (figure 1). These dikes were constructed by the USDI Bureau of Reclamation (USBR) to contain high flows that came from additional water added to the Provo River from transbasin diversions. With the loss of the meandering channel came loss of fish and wildlife habitat.

In 1992, Congress created the Utah Reclamation Mitigation and Conservation Commission (Mitigation Commission) to assure that mitigation for the Central Utah Project (CUP) and other Federal reclamation projects in Utah was accomplished. With the creation of the Mitigation Commission, new standards were imposed on mitigation projects that can be summarized as an “ecosystem restoration” standard. With this mandate, the Mitigation Commission was directed to support mitigation projects that integrated multiple aspects of the environment.

Fish and riparian habitat in the middle Provo River was severely degraded as the result of earlier actions taken to develop Provo River waters for agricultural, municipal, industrial, and other purposes. Knowing the past productivity of the middle Provo River for fish and wildlife habitat, interest turned to the middle Provo River as a site for CUP mitigation.

The Provo River Restoration Project (PRRP) involved removing or setting back most existing flood-control dikes, restoring meanders, and reestablishing a floodplain along the middle Provo River. The project began in 1999 and is anticipated to continue through 2006. In addition to fish and riparian habitat restoration, this project included acquisition of angler access, modification of diversion dams to bypass instream flows, and recreation facilities planning and development.

Physical and Biological Studies

The PRRP followed a management model where a great deal of planning and study preceded construction, which was followed by monitoring. An interdisciplinary team of scientists contributed their expertise to PRRP by designing and implementing several studies. These biological and physical studies provided three essential components for restoration: 1) a thorough description of the existing physical condition of biological communities (that is, baseline condition); 2) a basis for restoration design; and 3) initiation of monitoring that enables managers to detect measurable change due to restoration activities and to make informed management decisions.

Figure 1—Provo River in Heber Valley before restoration.

Scientists involved in the physical studies included hydrologists, geologists, and geomorphologists. To understand the character of the middle Provo River, scientists reviewed the geologic history and geological setting of the Heber Valley. This provided insight into the natural Provo River condition prior to human disturbance.

Hydrologists evaluated old hydrologic records and used computer simulations of natural conditions and stream gauge records to reconstruct natural Provo River hydrological conditions. Many plants and wildlife species are adapted to and depend on seasonal variations of natural flows. Using information from hydrology studies, the Commission worked with the Central Utah Water Conservancy District, Provo River Water Users Association, USBR, and others to implement flows that mimic natural flow patterns while continuing to meet water user needs.

The forces of flowing water carve a river channel. Channel size, shape, and pattern are related to flow magnitude, duration, and frequency as well as valley soils and slope. River mechanics experts determined the forces and sediment transport capability of the middle Provo River. With this data, designers identified expected channel characteristics and designed channels that will be sustained by natural processes. The channels also should provide flow depths and velocities consistent with native species habitat needs.

Biological Studies

Biological studies helped designers: 1) determine the condition of the biological community, 2) understand habitat needs of native plants and animals, and 3) plan for desirable habitat conditions for plants and animals. A primary PRRP goal was to increase game fish populations and suitable habitat. Restoring a meandering river channel has its most immediate effects on game fish populations by quickly increasing availability of cover, suitable spawning areas, and rearing areas. The Utah Division of Wildlife Resources has three fish population sampling stations on the Provo River within the Project area. Aquatic invertebrate monitoring is being conducted using intensive, semi-quantitative techniques to monitor changes in aquatic insect populations over time. Preliminary results bear out what was anticipated—early colonizers moved into restored sections within 3 months of construction. A year after construction, many of the common Provo River insects are once again abundant (URMCC 2003a).

Birds—Birds, especially migratory songbirds, were one of the main groups of wildlife used to develop habitat restoration guidelines. Scientists completed a 3-year baseline study that included habitat analysis (URMCC 2003b). The study related the abundance of riparian birds to vegetation types. A statistical habitat analysis involved a variety of vegetation attributes (such as tree density, number of tree species, wetland coverage, shrub coverage, and so on) and the presence of certain birds.

Small Mammals—Surveys of small mammals were conducted prior to restoration in the hopes of providing a baseline species list and recommendations for enhancements during restoration (Gannon and Sherwin 2001). These enhancements would be intended to restore mammalian diversity and abundance to historical levels prior to river channelization and intensive agricultural activity.

Plant Species—A botanical study was conducted along the PRRP corridor to ascertain physical requirements for establishing native riparian and wetland plants (Stromberg and others 1999). Plant species were combined into groups according to their requirements for soils, ground water, elevation, flow regimes, and location in relation to river and wetlands. The various requirements are being used for revegetating reconstructed stream banks and wetlands.

Construction and Revegetation Planning

Construction planning began with the end in mind and attempted to minimize the amount of land alteration. This yielded not only a cost benefit, but also lessened the impact to the environment. Careful planning for the construction phase was required in order to minimize materials handling (including the harvest, stockpile, and placement of topsoil), minimize grading for haulage equipment, and dispose of excess material onsite.

The harvest, stockpile, and placement of topsoil were planned carefully so that materials were handled as little as possible. Topsoil harvest, stockpiling, and placement guidelines used for the PRRP were as follows:

1) Topsoil should be stripped from all areas to a depth of 18 in (46 cm) or to a depth where significant (>50 percent) rock, stone, cobble, and so on are encountered, whichever comes first.

2) Subsoil with <40 percent rock, stone, cobble, and so on should be stockpiled separately.

3) Subsoil with >40 percent rock, stone, cobble, and so on should be stockpiled separately, used to construct features, or removed.

4) The top 12 in (30.5 cm) of soil from areas where weeds are common should be stripped and spoiled (bury it deep!).

5) Topsoil and suitable subsoil should be used to the maximum extent possible (no less than 1 ft [30.5 cm] of topsoil over subsoil).

6) Topsoil/subsoil should be placed following all construction and final grading, and just before planting, to avoid any activity that would result in compaction or that would require re-working the site.

7) Topsoil and subsoil should be transported/dumped in suitable locations/piles so that it can be spread with a backhoe bucket and not driven on (even by the backhoe) or compacted in any way.

Haul routes were minimized, and, to the maximum extent practicable, did not cross wetlands, wet areas, or constructed features. If crossing a constructed feature became necessary, compacted areas were ripped prior to topsoiling. No crossing was permissible on topsoiled areas (figure 2).

Onsite disposal of excess material can cause site impacts by disturbing additional area and possibly covering productive habitat. However, careful dispersal of excess material onsite will not only avoid transportation costs, but can reclaim disturbed habitats. For example, PRRP small mammal studies indicated that upland habitat for small mammals might be in short supply during high water events associated with periodic floods. For this reason, excess material has been used to raise the elevation of uplands in several areas in order to provide a refuge during high water events (figure 3).

Scope Of PRRP Revegetation

Prior to restoration, the Provo River main channel was about 10.4 mi (16.7 km) in length. Upon completion of the project, about 7.6 mi (12.2) of new channel will be constructed and 5.9 mi (9.5 km) of the original channel will have been converted to other wetland types. The result will be a Provo River main channel of about 12.1 mi (19.5 km) in length. To date, the PRRP has disturbed approximately 238 ac (96 ha) (table 1). To restore this area, 9,000 lb (4,080 kg) seeds have been broadcast, 388,000 bareroot or container plants have been outplanted (table 2) and 10,000 cuttings have been installed (willows or cottonwoods installed as

Figure 2—PRRP haul route. Note that the top foot of soil, which contains plant roots and seeds, has been stockpiled to the right of the road. This minimizes handling of the topsoil. Decommissioning of the route would follow the sequence of removing any road fill, grading to establish proper contour, ripping (if necessary), and replacement of topsoil.

Figure 3—Small mammal refuge created by onsite disposal of excess material.

Table 1—Area in acres (exclusive of haul routes, stockpiles and staging areas) disturbed each year of PRRP construction (1 ac = 0.4 ha).

1998	1999	2000	2001	2002	2003–2004	2005–006 (planned)	Total (planned)
18	27	34	76	16	67	66	304

Table 2—Number of bareroot or container seedlings outplanted each year.

1999	2000	2001	2002	2003	2004	2005	2006–2007 (planned)	Total (planned)
22,693	55,543	68,663	56,734	29,645	89,616	65,038	89,691	477,623

poles or wattles). It is anticipated that an additional 66 ac (27 ha) of disturbance will be restored in the next 2 years, requiring about 2,600 lb (1,180 kg) of seeds, 86,000 bareroot or container seedlings, and 2,000 willow or cottonwood cuttings.

Lessons Learned

Several important lessons learned by previous scientists were applied to the restoration of the Provo River, including: avoiding compaction; working with the natural disturbance regime of the river; and choosing the right plants for the site, including selection of the right size plant materials and outplanting at the appropriate density.

Compaction severely inhibits root growth and water percolation. To the maximum extent possible, activities that would result in compaction were avoided. It should be noted that working soils when they are at or near field capacity (wet) often results in significant compaction.

Wherever possible, it was important to work with the natural disturbance regime of the river. Figure 4a shows the natural recruitment of hundreds of seedlings within a high flow channel following a single flood event, and figure 4b the natural recruitment of hundreds, if not thousands, of seedlings following three flood events. No trees or shrubs were installed at this location, yet several cohorts of willow and cottonwood have successfully established because the natural disturbance regime of the river has been reestablished.

Research has verified that local adaptation promotes higher fitness under the specific ecological conditions of a site. Locally adapted populations often represent a "genetic memory" shaped by past selective events that, although infrequent (for example, 50-year freezes or 100-year droughts), are important agents of selection. The gene pool of plants well-adapted to local environments can be swamped through competition with a poorly adapted gene pool of nonlocal plants if they outnumber the local plants. To maintain the genetic integrity of the local plant community, we have prescribed that plant materials be collected within a 100-mi (160 km) radius of the project and from an area with an elevation ranging between 4,800 and 6,500 ft (1,460 and 1,980 m) above mean sea level (elevations found within the project).

Choosing the right plants for the site required that plants be installed in groupings that mimicked natural plant associations and at sites that were appropriate from a soil, water, and sunlight perspective. At PRRP, we installed only native

Figure 4—High flow channel one flood event after construction (A) and three flood events following construction (B). Note that no trees or shrubs have been installed at this location. Natural recruitment accounts for the many hundreds of seedlings.

species found within the corridor. Topsoil is quite uniform, so soil type was not a major consideration.

Selecting the right size plant materials required balancing the cost of the various sizes of plant materials and the cost of installing them with their availability and survival and growth rate. In general, larger plants are more expensive, require greater expense to outplant, and experience greater transplant shock.

In 2004, the cost (in U.S.$) of a bareroot seedling was about $0.80, with a cost to install of $0.39. For quart-sized materials, the seedling cost was about $2.00, with a cost to install of $1.85. At these costs, it was possible to install about three bareroot seedlings for every quart-sized seedling.

The following species outplanted as bareroot seedlings demonstrated particularly good survival and growth: cottonwood (*Populus angustifolia*), willow (*Salix lutea, S. lasiandra,* and *S. exigua*), Woods rose (*Rosa woodsii*), golden currant (*Ribies aureum*), red-osier dogwood (*Cornus sericea*), and boxelder (*Acer negundo*). Good results were obtained with bareroot chokecherry (*Prunus virginiana*) and serviceberry (*Amelanchier alnifolia*). Over all species, survival of bareroot seedlings after 1 year was estimated to be about 75 percent. The survival rate of quart-sized plant materials has not been estimated. However, even if assumed to be 100 percent, it is easy to see that the ratio of cost to survival favors planting bareroot seedlings as long as they are of good quality and available.

The planting density and floral composition (table 3) of shrubs and trees were selected based on the results of a study conducted by the University of Arizona (Stromberg and others 1999). In 1999 and 2000, we installed 1,700 shrubs/ac (4,250 shrubs/ha) and 400 trees/ac (1,000 trees/ha) in wetland/riparian areas. Because survival was higher than expected (75 versus 50 percent), in subsequent years we installed 1,200 shrubs/ac (3,000 shrubs/ha) and 300 trees/ac (750 trees/ha).

Table 3—Floral composition of plants installed at PRRP.

Common name	Percent of plants installed
Cottonwood	29
Boxelder	18
Alder	8
Woods rose	7
Dogwood	6
Hawthorn	6
Golden currant	5
Birch	4
Chokecherry	4
Serviceberry	4
Willow—Coyote	3
Willow—Pacific	3
Willow—Yellow	3
Honeysuckle	1

Typically, it is most desirable to broadcast seeds and install plant materials immediately prior to the period of greatest precipitation. For the PRRP, this would be in the fall, as most precipitation falls as snow between October and March. For this reason, we ordered plant materials to be delivered and outplanted in October 1999. The elevation of the PRRP ranges from about 5,000 to 6,000 ft (1,520 to 1,830 m) above sea level. The elevation at the nursery supplying most of the plants is about 4,500 ft (1,370 m) above sea level. Unseasonably warm fall temperatures at the nursery, coupled with an early winter storm at the PRRP, made it impossible to outplant the plants that fall. Plants were over-wintered at the nursery and outplanted the following spring. We have subsequently changed to an early spring outplanting of plant materials.

We learned that if we outplant all plant materials before May 1, our survival is quite good (about 75 percent after 1 year). Earlier seems to be better; however, unpredictable spring weather often delays outplanting, making it impossible to finish before May.

Irrigation can be a mixed blessing. Irrigation immediately after outplanting reduces transplant shock and may increase survival by eliminating air pockets in the soil that can desiccate roots. It can also encourage shallow root systems, with plants unable to withstand site conditions once irrigation is halted, and may encourage weeds.

Our plan was to set up irrigation equipment, but to only water when plants showed signs of significant stress, such as wilting or dropping leaves. We would only irrigate long enough to reverse the stress. With this strategy, we hoped to encourage plants to develop deep root systems. Beginning in 1999 and continuing through 2004, we experienced a severe drought. Precipitation between May and September was almost nonexistent, and what precipitation did occur came in very few large storm events. For this reason, we started irrigating the first week of June and continued through September of each year. However, in the summer of 2005, following a winter/spring of higher than normal precipitation, were we able to reduce our irrigation frequency and refrain from irrigating areas with a high groundwater table.

Results

PRRP wetland mitigation will be considered successful when the following criteria have been met for 3 consecutive years without intervention: 1) the relative cover of hydrophytic vegetation has been 50 percent or greater; 2) the relative cover of weeds has been less than 5 percent; and 3) soils have been stable. Results of the 2004 plant community survey indicated that at most monitoring sites (40 out of 66), the relative cover of hydrophytic vegetation was greater than 50 percent. To date, 20 sites have met all three success criteria for 3 consecutive years, and an additional 21 sites have met all three success criteria for the past 2 consecutive years.

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Chlorophyll Fluorescence: What Is It and What Do the Numbers Mean?

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Abstract: Although results of chlorophyll fluorescence (CF) measurements in nursery seedlings are becoming widely reported in the literature, the theory, terminology, and interpretation of these data are often obscure and confusing to nursery practitioners. This report outlines the underlying physiological basis for chlorophyll fluorometry and discusses measurement protocols and equiment. Interpretations of CF emissions are elucidated using heretofore unpublished data derived from Douglas-fir nursery seedlings.

Keywords: seedling physiology, stress physiology, Photosystem I, Photosystem II

Introduction

Optimum seedling physiological quality is central to achieving successful regeneration, vigorous first-year height growth, and green-up requirements. Seedling testing is an important tool for assuring that high quality seedlings are consistently delivered for field planting (Tanaka and others 1997). However, seedling testing is expensive and time-consuming.

For many years researchers have sought a "quick test" of seedling viability—a test that could be performed rapidly and easily immediately following a stress event—that would quantitatively indicate the level of damage that the plant had sustained and would predict subsequent plant performance. One emerging technology that has been developed in an effort to achieve this goal is called chlorophyll fluorescence (CF).

CF offers promise because it probes the inner mechanisms of the light reaction of photosynthesis, which is highly sensitive to stress (Krause and Weis 1991). As plants are subjected to various types of stresses (for example, cold damage, nutrient deficiency, disease), these can be detected, and sometimes diagnosed, by analysis of the fluorescence emissions emanating from $chlorophyll_a$ (Chl_a) in Photosystem II (PSII) of the light reaction (for example, Strand and Öquist 1988; Adams and Perkins 1993; Mohammed and others 1995 and references contained therein). Furthermore, CF analysis is rapid, nondestructive, and objective.

Although these techniques were developed in the 1930s (Govindje 1995), they have not been used in nursery seedling physiology research until recently because of the high cost and low portability of the instrumentation required. The advent of microprocessors, miniaturization, and advanced battery technology, however, has led to development of relatively low-cost, portable fluorometers capable of carrying out highly sophisticated field measurements.

Objectives

Unfortunately, CF terminology is confusing and often obscure to nursery practitioners. Yet the nursery literature contains a growing number of papers that report on the results of CF research as it applies to forest tree seedlings and regeneration. In recognition of this situation, this report has two objectives: 1) lay out a conceptual format that will enable nursery personnel to understand the physiological basis for the measurement of CF; and 2) provide baseline seasonal and diurnal profiles of several key CF parameters for "normal" Douglas-fir (*Pseudotsuga menziesii*) nursery seedlings that can be used to interpret CF information and literature reports.

The Physiological Basis of Chlorophyll Fluorescence

When radiant energy from the sun strikes a leaf, a portion of it is reflected, some is transmitted through the leaf, and the remainder is absorbed by the leaf. To avoid damage, the leaf must dissipate, or use up, all of this absorbed energy in some manner. This process is called energy "quenching." Three competing types of quenching are recognized. The first type is called photochemical quenching (qP) in which the light energy is converted to chemical energy that is used later to drive photosynthesis. Because the plant's light requirement for photosynthesis is often small relative to the absorbed light, much of this extra energy is dissipated as heat. This is called nonphotochemical quenching (qN). Finally, a small but important portion of the excess energy is given off as fluorescence emissions from chlorophyll molecules. This is called fluorescence quenching (qF).

Sometimes, under high light conditions, the plant may be unable to quench all the energy it absorbs. When this occurs, the excess energy fuels biochemical reactions that generate free radicals such as peroxides and other toxic oxygen species. The plant manufactures antioxidants to mop up these free radicals and render them harmless. However, these free radical scavenging systems can become overwhelmed, in which case the plant suffers from what is known as "photodamage" (Demig-Adams and Adams 2000). We sometimes see this in nursery crops. A good example would be greenhouse-grown hemlock (*Tsuga heterophylla*) stock that exhibits needle "scorching" following transplanting into a bareroot nursery.

Light energy enters the leaf of a plant and is "captured" by light harvesting pigments (figure 1). Depending on the wave length of the captured light, it enters one of two reaction centers called Photosystem I (PSI) and PSII, which are located on membranes in the chloroplasts. When a Chl_a molecule in PSII absorbs a photon of energy, one of its electrons is raised to a higher energy state. While in this state it is captured by an electron acceptor pool from which it funnels down through an electron transport chain into PSI, where a similar process occurs (PSI and PSII are named in the order in which they were discovered, not the order of the reaction). In PSI, the photochemical process generates NADPH that provides the energy for turning CO_2 into sugar in what is known as the "Calvin Cycle." In this manner, the light reaction converts absorbed light energy into stored chemical energy.

Another key part of the light reaction is called "water splitting." In order to replenish the electrons that are lost from Chl_a in PSII, the plant splits water molecules, releasing oxygen atoms into the atmosphere and providing electrons that feed into PSII.

For any of a number of reasons, many of the excited electrons from Chl_a in PSII are not captured by the acceptor pool and they decay back to their ground state. The energy lost in this decay process is given off as fluorescent light (fluorescence quenching). This is shown in figure 1 as a wavy line. It is this emission of fluorescent light that is measured in chlorophyll fluorescence.

Measurement of Chlorophyll Fluorescence (CF)

Kautsky Fluorometers

Observations of chlorophyll fluorescence were first reported by Kautsky and Hirsch in 1931 (Govindje 1995). They acclimated plant cells to darkness for several minutes, clearing all the excited electrons from the electron transport chain and emptying the acceptor pools. Then they exposed the cells to a brief pulse of high intensity photosynthetically active light and monitored the rise and fall of the ensuing fluorescence emission with a sensitive photometer. What they observed was similar to the curve in figure 2. These

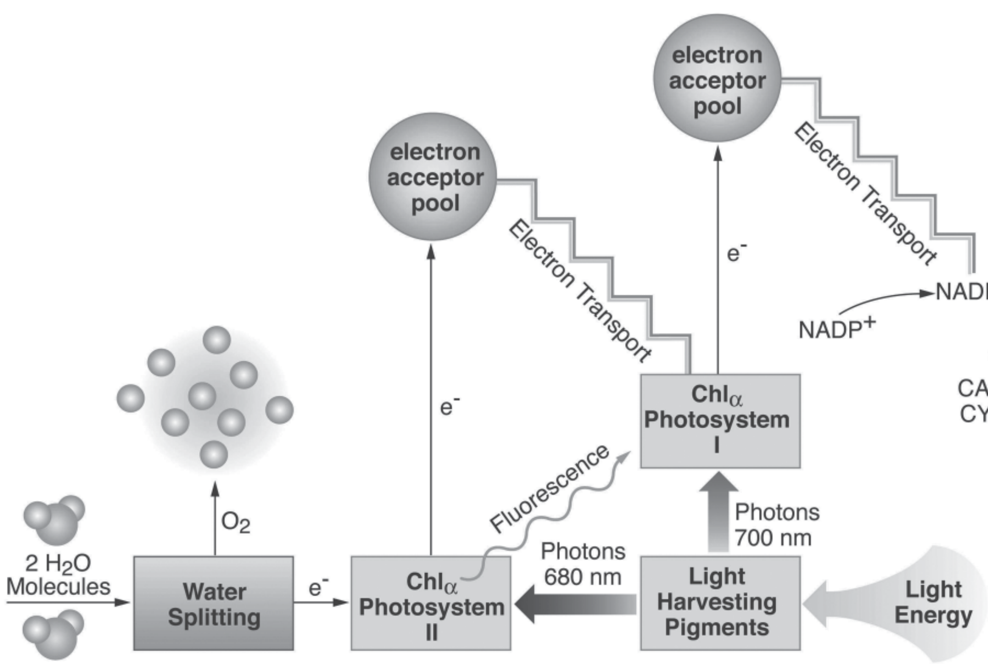

Figure 1—Simplified diagram of the "light reaction" of photosynthesis. Chlorophyll fluorescence emanates from $chlorophyll_a$ in Photosystem II.

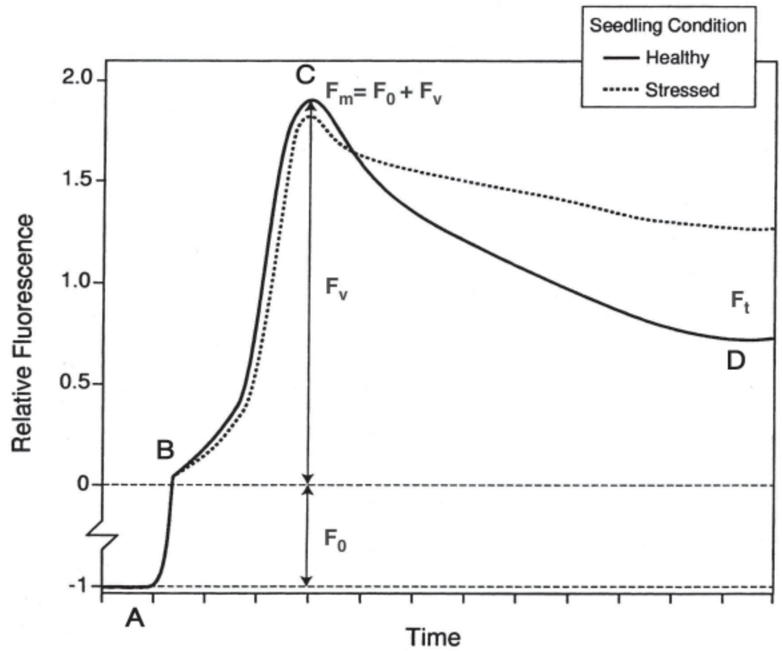

Figure 2—A typical chlorophyll emission curve for a leaf made with a "Kautsky" fluorometer. A is at the point of the actinic light pulse; B is the chlorophyll emission when all reaction centers are open; C is the emission peak; and D is the emission approaching steady state. F_o is the fluorescence emanating from the light harvesting complex. F_m is maximum fluorescence. F_v, variable fluorescence = $F_m - F_o$. F_t is steady state fluorescence. If the leaf is under significant stress, say from cold damage, the emission curve may resemble the upper dotted line.

observations led to the development of what are now known as "Kautsky" fluorometers, which generate similar curves to that in figure 2.

In a "Kautsky curve" (figure 2), emissions rise to a point, F_o, which represents fluorescence where all reaction centers are open and qP is maximal. Then, there is a sharp rise to a point of maximum fluorescence (F_m). The rise from F_o to F_m is called "variable fluorescence," or F_v. F_m is transient, giving way rapidly to a marked decrease, then a gradual decay to the steady state, F_t. Note that when the plant is under significant stress, the emission peak continues unabated for a long period of time. This is evidence that healthy cells are able to "quench" light energy while killed or damaged cells are not.

A key observation was made by Genty and others (1989). They showed that the ratio of F_v/F_m is a direct measure of the "optimal quantum efficiency" of the plant. This is a very important plant property that indicates how efficient the light reaction is proceeding. It has a theoretical maximum value of about 0.83. Many studies using Kautsky-type fluorometers report primarily this value as the results of their analysis (for example, Fisker and others 1995; Binder and Fielder 1996; Perks and others 2001; Perks and others 2004).

Pulse Amplitude Modulated (PAM) Fluorometers

During the 1980s, workers in Germany developed a novel fluorometer called a pulse amplitude modulated (PAM) fluorometer (Schreiber and others 1995). With this instrument, the initial light pulse is followed by a series of rapid pulses of very high intensity saturating light (up to 6,000 $\mu mol/m^2/s$) that overwhelm the acceptor pools, thus canceling out qP. The fluorescence emission difference between these peaks and the fluorescence decay curve is, therefore, qN. This is often called a "quenching analysis" because it provides separate estimates of the three components of quenching. It turns out that this type of analysis is a powerful tool for evaluating plant stresses. In theory, qP represents the more "desirable" form of quenching in which light energy is converted to chemical energy (figure 1). In contrast, qN can be thought of as "back up" quenching, or venting off of excess energy with no gain to the plant. While plants generally rely on both qP and qN to dissipate energy, as they come under stress, qP tends to remain relatively constant while qN tends to increase. We will see examples of this later.

Equipment—Fluorometers of both types (Kautsky and PAM) contain similar components. These include a light source, two filters, a photo sensor, and a fiber optic cable with an attached leaf clip (figure 3). The unit interfaces with a laptop computer. Prior to measurement, the subject leaf is darkened for 20 to 30 minutes. The leaf clip is attached to the leaf, then the light source gives off a strong pulse that travels first through a filter that passes photosynthetically active radiation, then through the cable to the leaf. Fluorescent light emitted by the leaf passes back through the cable, through the second filter to the photo detector, which measures its intensity for approximately 5 minutes. This is then recorded and calculations of CF parameters are made by the computer. From this analysis Kautsky fluorometers yield the values shown in appendix 1A; PAM fluorometers yield these same values plus those shown in appendix 1B. Note that Kautsky fluorometers are not capable of estimating quenching coefficients, which greatly limits their usefulness.

"Normal Values" of CF Parameters

Discussions with other scientists, notably Mohammed (2005), as well as perusal of the CF literature led to the development of table 1. This gives what are often considered

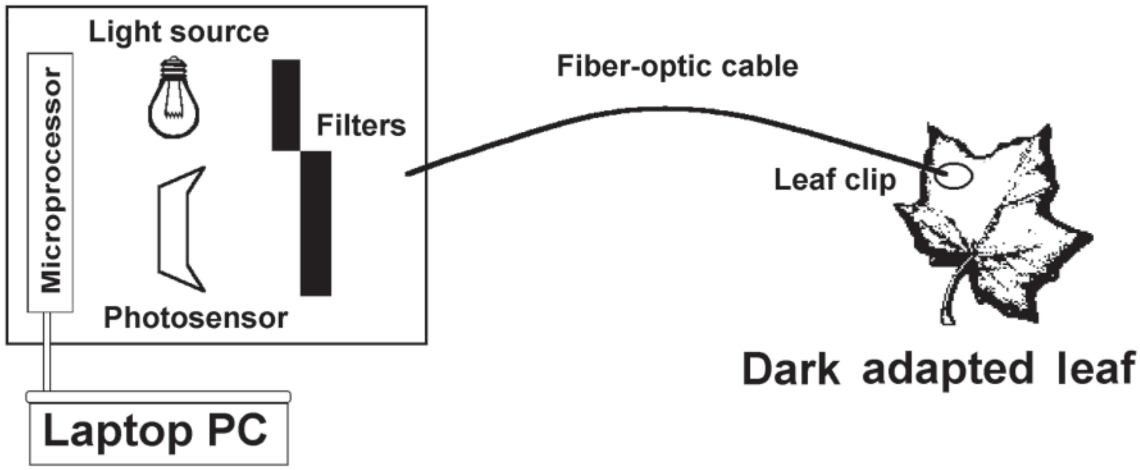

Figure 3—Diagram of a typical chlorophyll fluorometer. An actinic light pulse generated by the light source travels to a dark adapted leaf through a fiber optic cable. Fluorescence emissions from the leaf return through the cable to the photosensor. The emission curve and emissions parameters are generated by the microprocessor. The instrument interfaces with a laptop PC.

Table 1—"Normal values" of CF emissions parameters in plants extracted from the literature and Mohammed (2005). See appendix for parameter definitions.

Parameter	"Normal" value	"Stress" value
F_o	0.2 to 0.4	>0.7 indicates low absorption in chlorophyll antenna bed due to chlorophyll breakdown or reconfiguration
F_m	1.2 to 1.5	
F_t	$F_t \sim F_o$	low F_t
F_v/F_m	Approximately 0.700 to 0.830	<6.0
Y	0.40 to 0.60	0.1 to 0.2
qN	0.4 to 0.6	prolonged values > 6.0
qP	0.7 to 0.8	prolonged values < 6.0
ETR (in full sun)	<300 electrons μmol/m^2/s	

to be "normal" values for the CF parameters shown in appendix 1. These, then, will be used as a template against which to compare the Douglas-fir values reported below.

CF Emissions From Healthy Douglas-Fir Nursery Seedlings

In spring 1997, we transplanted 1+0 Douglas-fir seedlings directly from freezer storage into a nursery in western Washington where they were grown as an operational crop. We monitored CF emissions from these seedlings on a regular basis through a 1-year growing cycle using a PAM fluorometer. Temperature and light conditions were also recorded during the measurement period.

Fluorescence Emissions Immediately Following Transplanting

The first thing we noted was that seedlings recovered from freezer storage quite rapidly. F_o, F_m, and F_v/F_m stabilized within 3 days (figure 4). At the time of planting, F_o ranged from 0.2 to 0.4, which is considered to be normal for most plants (table 1), while F_m began low but immediately climbed to within its normal range (approximately 1.2 to 1.5) and remained there. F_v/F_m began at about 0.60, but climbed to nearly 0.80 within 1 day and remained there. An F_v/F_m value of 0.60 is relatively low (remember the optimum is 0.83), but probably not low enough to indicate a significant stress.

The quenching coefficient qP remained within a range of about 0.7 to 0.8 throughout the period (figure 5). In contrast, qN began at a very low value and increased sharply 2 days after planting to briefly exceed qP. It then decreased gradually until, approximately 2 weeks later, it reached steady state at about 0.5, which is within the normal range. This suggests that some enzyme(s) required for one of the qN reactions may have degraded in frozen storage but was renewed within several days after planting. Later in summer, qN rose to meet qP as midday light intensity increased.

Diurnal Profiles of Fluorescence Emissions

Diurnal CF profiles differed between cloudy and sunny days. For example, on cool cloudy days, when the incoming photosynthetically active radiation (PAR) did not exceed 200

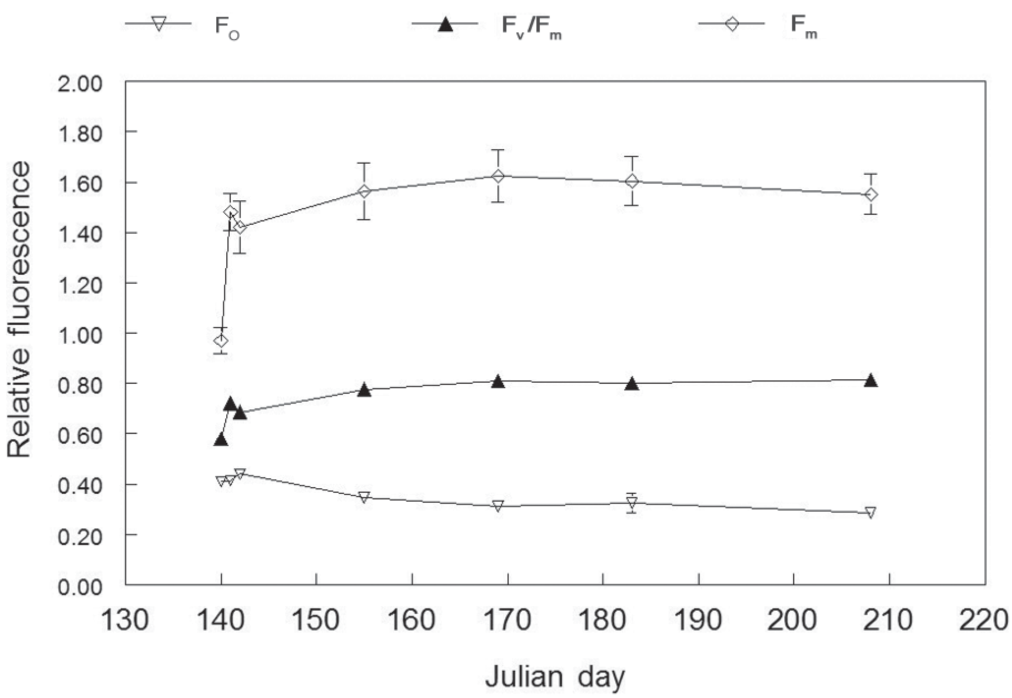

Figure 4—F_o, F_m, and F_v/F_m of 1-year-old Douglas-fir seedlings immediately after their removal from frozen storage and transplanting into a nursery bed (Julian Day 140). Each data point represents a mean ±1 SE of nine seedlings.

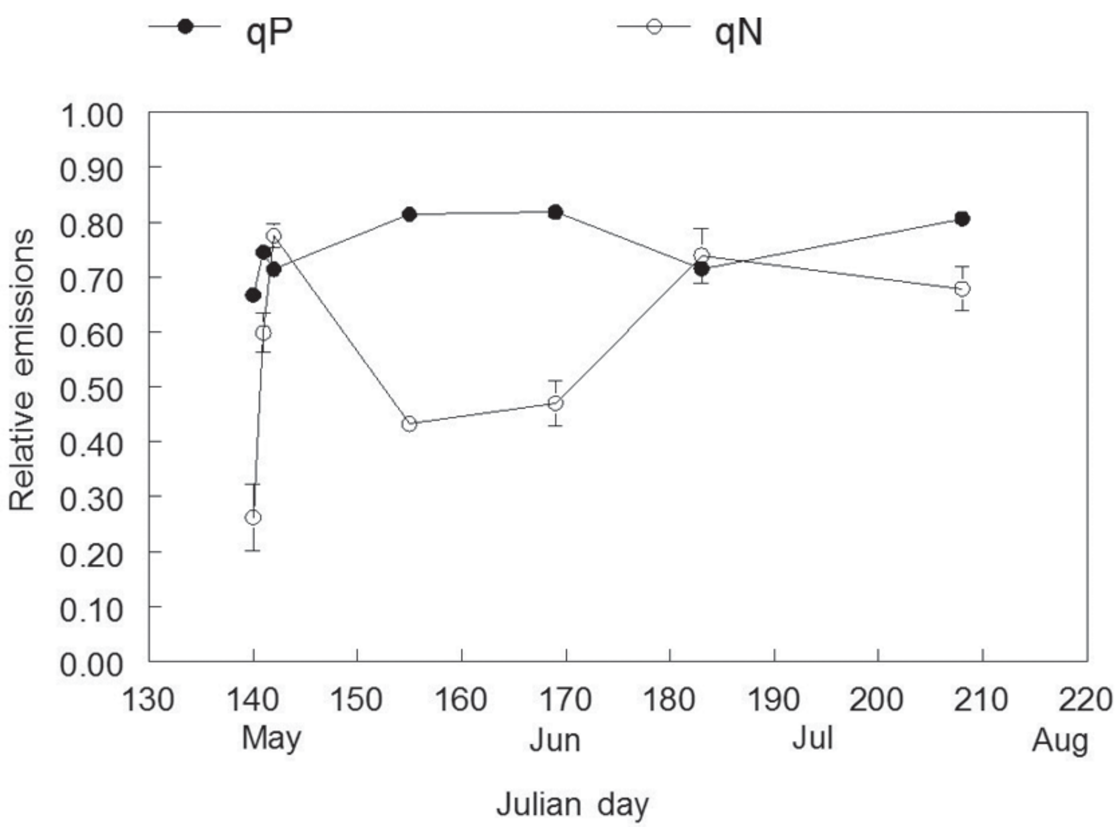

Figure 5—Quenching coefficients, qP and qN, from 1-year-old Douglas-fir seedlings immediately after their removal from frozen storage and transplanting into a nursery bed (Julian Day 140). Each data point represents a mean ±1 SE of nine seedlings.

µmol/m^2/sec (full sunlight is about 2,000 µmol/m^2/sec), F_v/F_m and qP remained near 0.80 all day, while qN remained below 0.6 (figure 6). This suggests that at low light intensity, photochemical quenching was "using up" most of the incoming light energy, so the plant didn't have to rely much on qN for energy dissipation. In contrast, on a bright sunny day (midday PAR = 1,800 µmol/m^2/sec), while F_v/F_m and qP remained near 0.80, qN rose sharply, exceeding qP much of the day (figure 7). The interpretation here is that qP was saturated so that backup quenching was called upon to help dissipate the excess energy. Slight depressions in F_v/F_m and qP in late afternoon further indicate slight stress.

The quenching coefficients are very sensitive stress indicators (Lichtenthaler and Rinderle 1988); qP is a relatively fixed property, changing only slowly in response to light adaptation. On the other hand, qN is plastic, adjusting rapidly as stress increases or decreases. This illustrates the elegant sensitivity with which the seedlings were able to respond to rapid changes in light intensity on a short term basis.

Responses to Cold Weather—At the outset of this study, we had hoped for a winter arctic front that would appreciably affect the seedlings so that their response to such an event could be observed. Unfortunately (or fortunately), there was no such event during the very mild winter of 1997 to 1998. Only one cold, snowy episode occurred during the week of January 7 to 15 (figure 8).

Temperatures began falling to below freezing on the night of January 9 and remained below freezing for four consecutive nights. Several inches of snow fell on January 10 to 11, blocking nearly all light from the seedlings. The snow melted and temperatures began to climb to 40 °F (4 °C) beginning January 13. Some key CF responses to this event are shown in context of the overall seasonal patterns in figure 9.

After the initial transplanting recovery phase, F_v/F_m remained near 0.80 throughout the year and did not show any response to the cold event; qP also remained high throughout the year. However, it exhibited a sharp, but temporary, drop to about 0.15 immediately following the cold event. In contrast, qN varied considerably, being relatively high during the sunny summer months and lower during fall, winter, and spring. During the cold event, as qP dropped, qN increased sharply.

The low temperatures that occurred during that cold event were not lethal to Douglas-fir seedlings at that time of year, which have LT_{10} and LT_{50} temperatures approximately –15 °C (5 °F) and –18 °C (–0.4 °F), respectively (Y. Tanaka, unpublished data). Therefore, no significant damage would be expected. With this in mind, the following interpretation is offered. The cold event (perhaps coupled

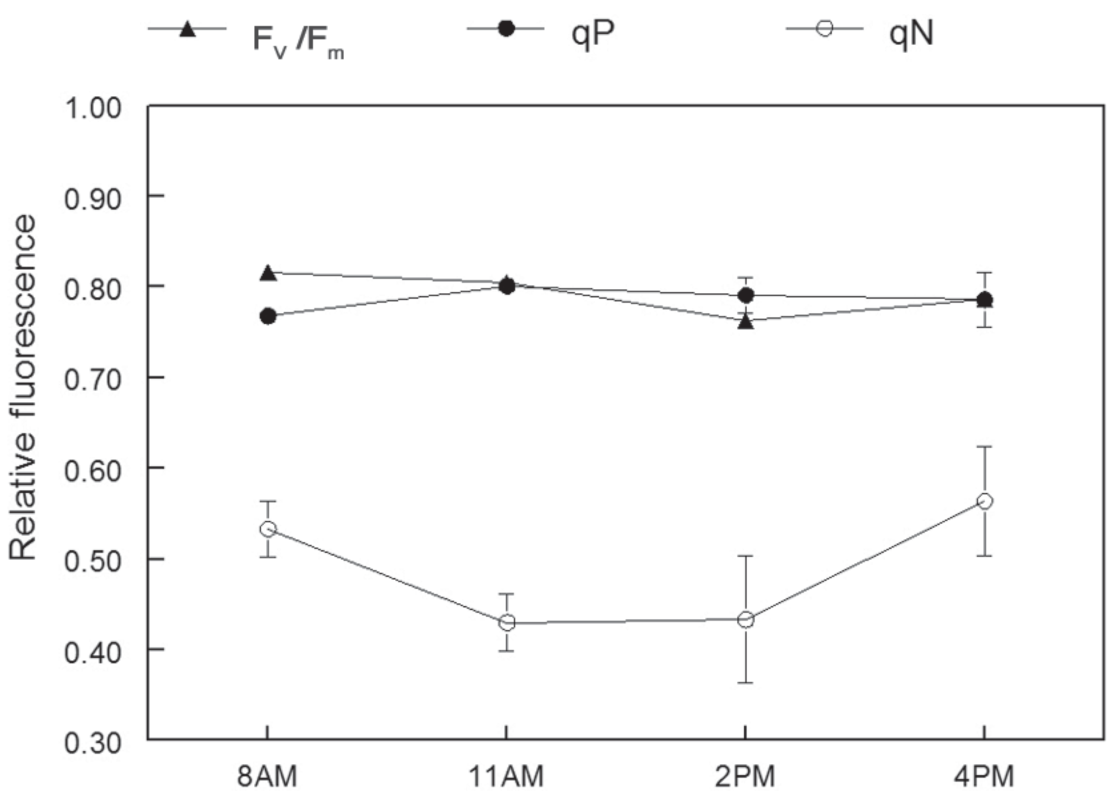

Figure 6—Diurnal trend of F_v/F_m, qP, and qN for 2-year-old Douglas-fir seedlings on a dark, cloudy day. Each data point represents a mean ±1 SE of nine seedlings.

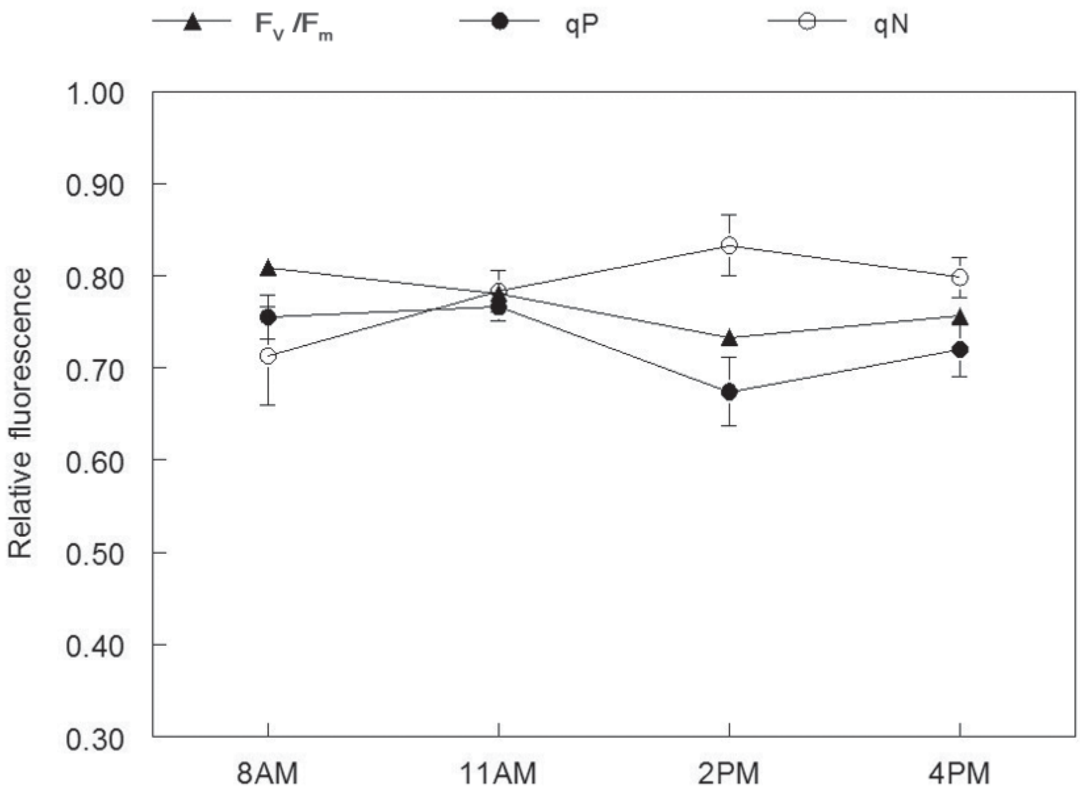

Figure 7—Diurnal trend of qP and qN for 2-year-old Douglas-fir seedlings on a bright, sunny day. Each data point represents a mean ±1 SE of nine seedlings.

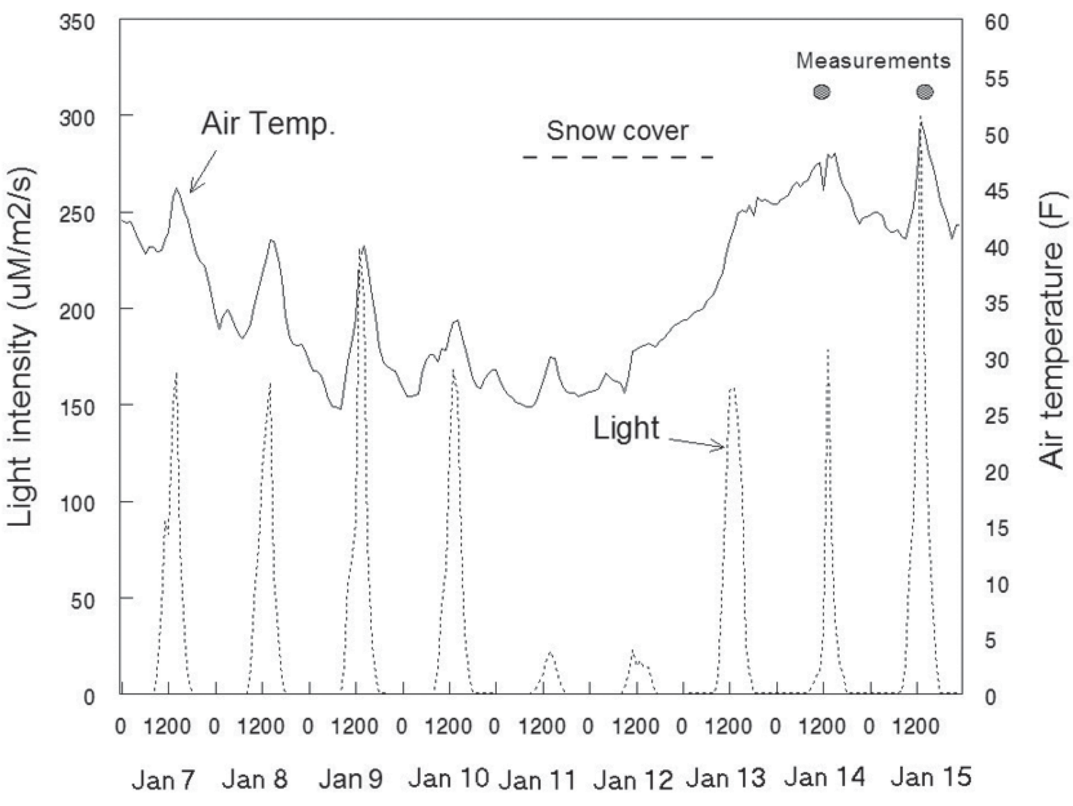

Figure 8—Record of air temperature, light intensity, and snow cover for a cold period in January 1998. Douglas-fir seedlings were covered with snow January 11 to 13. Large dots indicate times that CF emissions were measured on these seedlings.

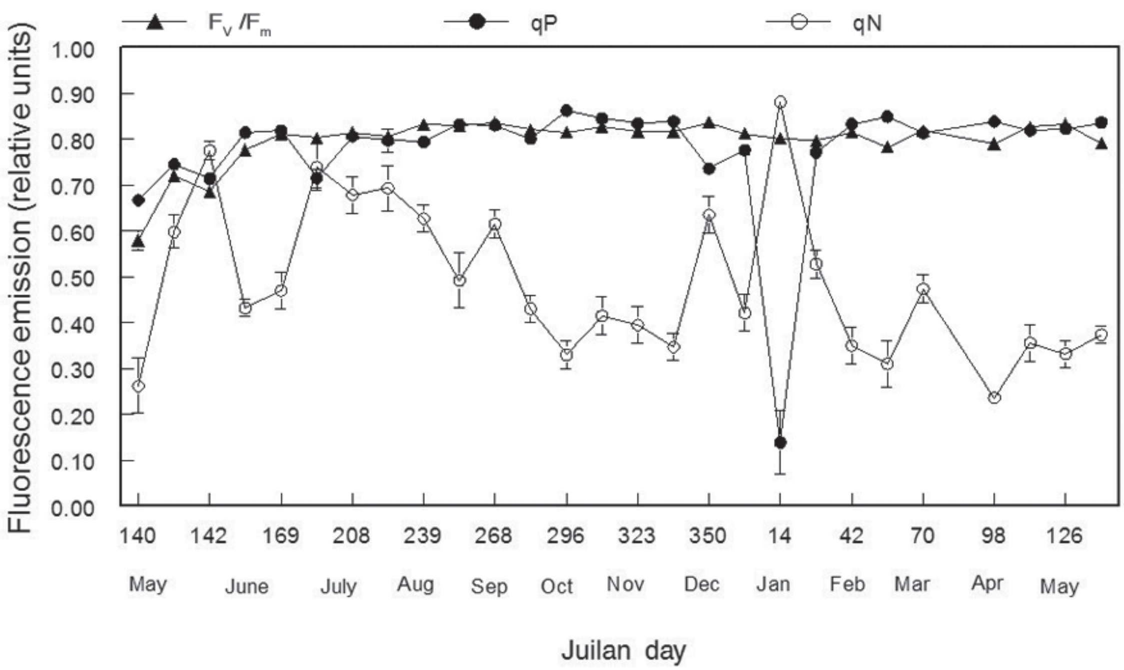

Figure 9—Seasonal trend of F_v/F_m, qP, and qN for Douglas-fir nursery seedlings showing changes in qP and qN immediately following a cold event in mid-January (see figure 8). Each data point represents a mean ±1 SE of nine seedlings.

with 3 days of near darkness beneath snow) resulted in a slight and transient stress in the seedlings. Their response was manifest as a temporary disruption of qP that was compensated by a sharp increase in qN. This stress abated with a return to lighter, warmer conditions, and CF parameters returned rapidly to normal. An important point is that F_v/F_m did not respond to this event, indicating its robustness and stability.

Because of its robustness, F_v/F_m has often been used to quantify damage from severe freezing. An example of this comes from the work of Perks and others (2004). They subjected foliage of Douglas-fir seedlings to CF analysis following exposure to subfreezing temperatures while they were dehardening during February, early and late March, and April. At each test date, subfreezing temperatures depressed F_v/F_m from near 0.8 to below 0.4 (figure 10). As the seedlings continued to deharden, the F_v/F_m values became more depressed by low temperatures. For example, a temperature exposure of –20 °C (–4 °F) had no effect on F_v/F_m in February, but in late March the same temperature depressed F_v/F_m to 0.2. The authors propose, as have others, that F_v/F_m following freezing can provide a simple, rapid, and accurate prediction of cold tolerance.

Summary and Conclusions

Plants have evolved intricate mechanisms for dissipating, or quenching, the light energy they absorb. Some of this energy is used in photosynthesis (photochemical quenching, qP), while the remainder is dissipated by nonphotochemical (qN) or fluorescence (qF) quenching. Stress caused by high and low temperature, disease, inadequate nutrition, and so on impairs a plant's ability to manage energy quenching. Thus, by measuring and interpreting the three components of quenching using chlorophyll fluorescence (CF), it is possible to detect damage resulting from subtle, transient stress as well as long term, severe stress. Three important CF parameters that are often reported in the nursery literature are qP, qN, and F_v/F_m.

qP has a normal range of between 0.7 and 0.8. Diurnal variability is low but seasonal variability can be moderate to high. qP often falls during or after stress events but can recover rapidly as damaged tissues and reactions are repaired by the plant.

qN has a much broader normal range, varying from about 0.3 to 0.7. Diurnal and seasonal variability are high, so qN is a very sensitive indicator of stress. Very slight stresses can cause relatively large changes in qN.

F_v/F_m (optimal quantum yield) has a normal range of 0.7 to 0.8, is seasonally and diurnally stable, and is therefore a robust seedling damage indicator. Only severe stress can cause a significant reduction in F_v/F_m. For this reason it is often used to detect severe cold damage. When this value falls below about 0.6 it may be cause for concern.

Damaged or stressed plants have the ability to recover quickly, so it is important to measure CF parameters over a course of several days following stressful events before conclusions about plant damage can be reached. If F_v/F_m remains low and qN high for several days, this indicates that significant damage to the photosynthetic system has probably occurred.

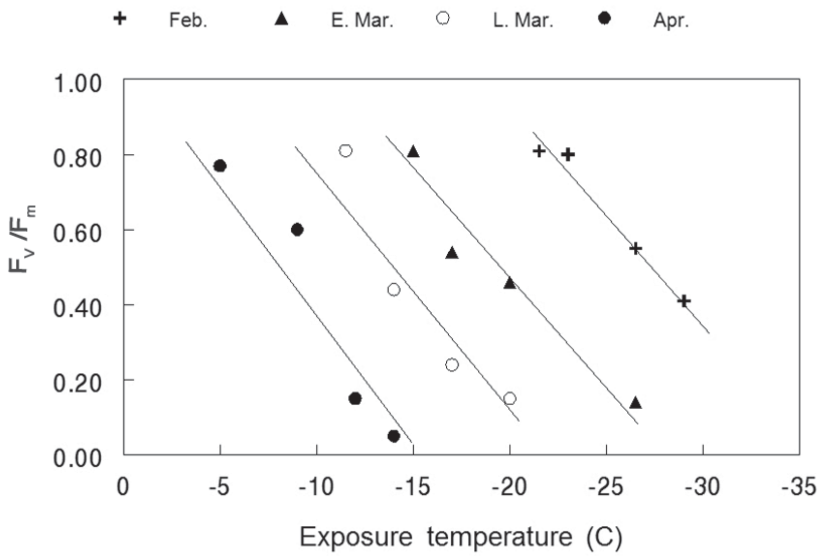

Figure 10—F_v/F_m values measured on Douglas-fir seedling needles following exposure to subfreezing temperatures during dehardening in February, early and late March, and April (modified from Perks and others 2004).

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Appendix 1A—Chlorophyll fluorescence (CF) emissions parameters yielded by a "Kautsky" fluorometer.

Parameter	Definition	Description
F_o	Original fluorescence	Fluorescence which emanates from the light-harvesting pigments of the leaf; generally considered a "background level" fluorescence which is zeroed out when measuring PSII chlorophyll fluorescence.
F_v	Variable fluorescence	Height of the fluorescence peak above F_o following exposure to the actinic light pulse.
F_t	Fluorescence at steady-state	Height of the fluorescence peak 5 minutes following the end of the light pulse.
F_m	Maximal fluorescence	$F_v + F_o$
F_v/F_m	Optimal quantum yield	An estimate of the ratio of moles of carbon fixed per mole of light energy absorbed (Genty and others 1989); theoretical maximum value for C_3 photosynthesis is approximately 0.830.

Appendix 1B—Additional CF emissions parameters yielded by a PAM fluorometer.

Parameter	Definition	Description
qP	Photochemical quenching	Absorbed light energy that is dissipated (quenched) through electron flow in the light reaction).
qN	Nonphotochemical quenching	Absorbed light energy that is dissipated largely through sensible heat loss and other non-photochemical mechanisms.
Y	Effective quantum yield	The actual quantum yield at a point in time; Y is generally much lower than the optimal quantum yield.
ETR	Electron transport rate	Empirical estimate of the rate of flow of electrons through the electron flow pathway.

Run for Cover! What's Covering Your Greenhouse and How Is It Affecting Seedling Growth?

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Abstract: Analysis of seedling growth characteristics between two greenhouse cover types, old fiberglass and new polycarbonate, shows significant differences in height and sturdiness coefficients in ponderosa pine (*Pinus ponderosa*) seedlings. Three rates of nitrogen (N) application (20, 40, and 60 mg) indicate that seedling growth will increase under both cover types, but may cause a reduction in seedling quality attributes including shoot-to-root ratio and seedling sturdiness. Under the new polycarbonate cover type, the mid and high rates of N fertilizer application showed no significant gains in seedling growth. Significant differences in germination were also detected between the two cover types favoring the old fiberglass material. When considering replacing a greenhouse cover with a new material, it is important to consider alterations in the seedling growth environment and make the appropriate cultural adjustments to ensure high seedling quality.

Keywords: greenhouse cover, greenhouse glazing, light, seedling growth, *Pinus ponderosa*

Introduction

The greenhouse environment has long been used for the rapid establishment of outplantable trees for reforestation. Over the years, the variety of propagation environments has increased to suit the demands of growers and clients to produce the optimal target seedling. Despite the vast variety of propagation structures available, greenhouses have maintained a common set of properties to achieve a favorable growing environment. The ideal greenhouse environment utilizes cover materials that favor the capture of sunlight while maintaining temperature, humidity, and CO_2 for a specified crop (Nijskens and others 1985; Landis and others 1994). More specific ideal radiometric properties call for maximal transmittance in the photosynthetically active radiation (PAR) spectrum (400 to 700 nm) and minimal transmittance in the far-infrared spectrum (>1,000 nm) to produce the desired "greenhouse effect" (Nijskens and others 1985).

Greenhouse cover materials, or glazings, come in numerous varieties, each with its unique set of properties as they relate operationally and physically. Table 1 summarizes three commonly used types of material. When planning to build or re-cover a greenhouse, certain considerations should be made regarding cost, life span, strength, weight, light transmittance, and thermal conductance (Landis and others 1994; Evans 2003).

Each of these properties plays a critical role in greenhouse structure, but long-term planning should consider the effects of life span and light transmittance. Typically, shorter life span materials will cost less, allowing for regularly scheduled replacement. In cases where material remains in place longer than its life span, specifically fiberglass cover materials, significant reductions in light transmittance can be observed. Therefore, with one of the four atmospheric components (light, humidity, carbon dioxide, and temperature) necessary for growth in limiting supply, optimal seedling growth can be compromised (Kozlowski and Pallardy 1997). To fully understand the consequences of a reduced light growing environment, a review of the nature of light is necessary.

Table 1—Operational and physical considerations of three common greenhouse cover types (adapted from Landis and others 1994; Evans 2003).

	Operational considerations			Thermal	□
Material	**Advantage**	**Disadvantage**	**Light (%PAR)**	**conductance**	**Lifespan**
				(BTU loss/ft^2/hr/(ΔF))	*years*
Fiberglass	Low cost, strong, light-weight	Surface degrades easily, highly flammable	90 single layer	1.2	3–10
			70 double layer	<1.2	3–10
Polyethylene	Low cost, light-weight, easy to install	Short life, high thermal conductance	85 single layer	1.2	2–3
			76 double layer	0.7	2–3
Polycarbonate	High impact resistance, low flammability	High cost, high expansion and contraction	94 single layer	>0.5	20–25
			83 double layer	0.5	20–25

The electromagnetic radiation emitted from our sun covers a broad spectrum of wavelengths from high energy, short wavelength ultraviolet rays to low energy, long wavelength radio waves (Grossnickle 2000; Larcher 2003). Within this range of wavelengths, three properties of light (intensity, duration, and quality) are known to influence the two physiological plant growth factors of photosynthesis and photomorphogenesis, defined below (Kozlowski and Pallardy 1997; Grossnickle 2000; Larcher 2003). Wavelengths ranging from 400 to 700 nm are collectively categorized into the visible spectrum and are also associated with photosynthetically active radiation (PAR). Photosynthesis produces chemical energy for plant growth and metabolism with signature wavelengths peaking at 430 and 680 nm; these wavelengths are captured by carotene and chlorophyll pigments (Landis and others 1994). Morphological development, including branching, shoot elongation, shoot sturdiness, seed germination, and budset, are influenced by the visible and near infrared light spectrum (700 to 1000 nm) via phytochrome and other pigments. These responses are termed photomorphogenesis (Landis and others 1992; Grossnickle 2000). Of the four atmospheric factors that influence seedling growth, photosynthesis and photomorphogenesis are highly influenced by the light aspect, but photosynthesis is also influenced by temperature (Landis and others 1992).

As temperature increases, photosynthesis also increases curvilinearly. At the same time, the reciprocal process of respiration increases exponentially. As long as total photosynthesis exceeds respiration, net photosynthesis is positive. When the maximum temperature for photosynthesis is reached, however, the net photosynthetic gain will be lower than the respiration rate. Depending on different types of greenhouse cover types, and their thermal conductance capabilities, different temperatures within the greenhouse will have a significant impact on seedling growth as illustrated by this principle (Landis and others 1992).

Changes in greenhouse cover type can have a significant impact on seedling growth as illustrated by modifications of the light environment and the subsequent effects of changes in temperature. Our study objective was to examine the direct effects of an old fiberglass greenhouse cover and a new polycarbonate cover on seed germination and seedling growth. The addition of three fertilizer treatments provided information on the degree at which nutrient availability would compensate for shade effects. Direct effects measured are morphological traits including height, root collar diameter (RCD), seedling biomass, shoot-to-root ratio, and sturdiness coefficient. Examinations of germination percentages and rates, light absorption spectra, and light quality will supplement findings in the direct effects.

Materials and Methods

Nursery Culture

Ponderosa pine (*Pinus ponderosa* Laws. var. *ponderosa*) seedlings from an Idaho Department of Lands seed source (850 m [2,790 ft] elevation; seedlot CO85) were grown at the University of Idaho Center for Forest Nursery and Seedling Research (UI) in Moscow, Idaho (46º 43'N, 117º 00'W). Seedlings were sown in a 2 by 3 factorial design with three replicates per treatment. Treatments consisted of two cover types and three fertilizer rates. Six small growing structures were constructed using the two cover types. Three structures were built from old fiberglass (approximately 25 years old) belonging to the previous UI greenhouse, and the remaining three were constructed from the new twin-wall polycarbonate material used on the newly erected UI greenhouse (figure 1). Each structure represented a replicate containing each of the three fertilizer treatments. Structural dimensions were approximately 1.5 by 0.7 by 0.9 m (5 by 2.3 by 3 ft) with a single 45° sloped roof.

The north side of each structure remained open for ventilation and had a removable plastic cover to protect seedlings from cold nighttime temperatures. The remaining three sides were covered by the respective greenhouse cover with the exception of approximately 15 cm (6 in) at the bottom for ventilation. All structures were elevated above ground on a wire mesh bench. Stratified seeds were hand sown 21 May, 2002 into Styroblock™ 315B containers having a 90-ml (5.5-in^3) volume and 756 m^2 (70.6 ft^2) density (Beaver Plastics, Edmonton, Alberta) and containing a sphagnum peat moss:vermiculite (1:1, v:v) medium (Sun Gro Horticulture, Bellevue, Washington). Target® Forestry Nursery Grit (Target Products Ltd., Burnaby, British Columbia) was used to cover the freshly sown seeds. Cavities were thinned to one seedling 2 weeks after sowing.

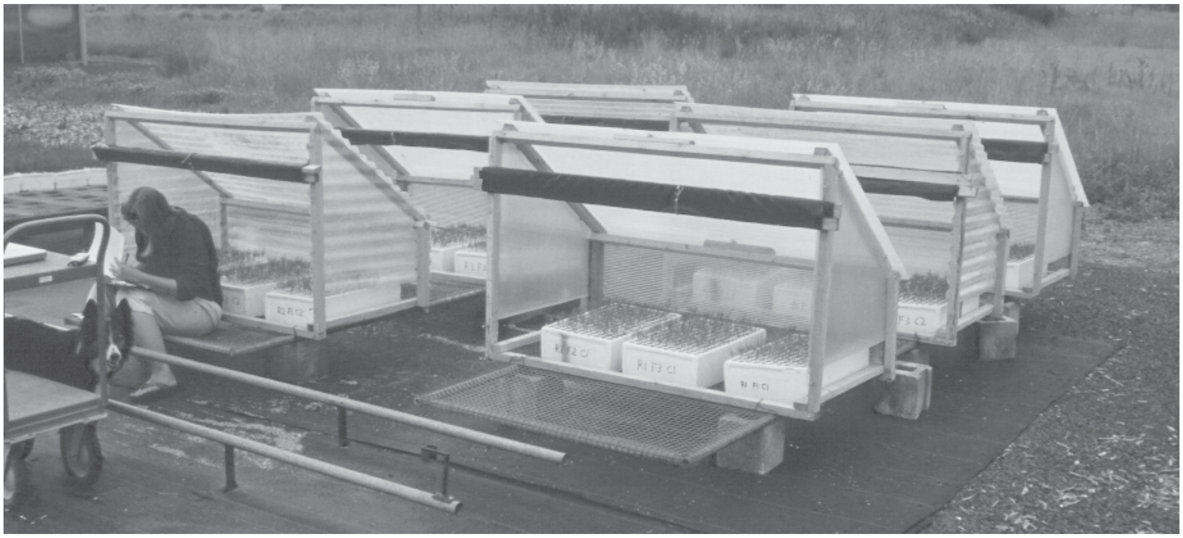

Figure 1—Six small growing structures, three made from old fiberglass and three made from new polycarbonate, used to produce *Pinus ponderosa* seedlings for one growing season at the University of Idaho Center for Forest Nursery and Seedling Research, Moscow, Idaho.

Fertilizer treatments were divided into three levels of total nitrogen (N) applied: 20, 40, and 60 mg. Exponential fertilization was carried out for the duration of the experiment. The basic formula for exponential fertilization is

$$N_T = N_S\,(e^{rt} - 1)$$

where r is the relative addition rate required to increase N_S (initial N content in plant) to a final N content ($N_T + N_S$) where N_T is the desired amount to be added over t, the number of fertilizer applications (Ingestad and Lund 1986; Timmer and Aidelbaum 1996). Using an estimate of 0.5 mg for N_S, 119 days for t, and the target N_T value (20, 40, and 60 mg), the relative addition rate r was calculated for each treatment, 0.031, 0.037, and 0.040 respectively. The amount to apply on a specific day was calculated using

$$N_T = N_S\,(e^{rt} -1) -N_{t-1}$$

where NT is the amount of N to apply daily, N_{t-1} is the cumulative amount of N applied, and t goes from 1 to 119.

Because root exploitation of the growth substrate is lacking immediately after germination, compensation for the small amount of N applied during the first 2 weeks was calculated using

$$N_C = N_S\,(e^{rt} -1)$$

where N_C is the mg of N to compensate, N_S is the initial N content in the plant, r is the relative addition rate, and t equals the compensation period (assumed 14 days). For all three treatments, N_C equaled the cumulative amount N scheduled to be applied on days 118, 119, and 120 (1.9, 4.4, and 7.2 mg N rates for 20, 40, and 60 mg N applied, respectively). The daily amount of N compensated was calculated using

$$N_T = N_S\,(e^{rt} -1) - N_{t-1}$$

where t went from 14 to 0. Therefore, plants received N_T plus N_C for the first 14 days and no additional fertilizer on days 118, 119, and 120. Intervals between fertigation events varied, so daily N_T values were summed with the cumulative amount applied when irrigation was necessary. N treatments were fertigated with $20N{:}7P_2O_5{:}19K_2O$ (Peters Professional® Conifer Grower™, The Scotts Company, Marysville, Ohio), and application was gravimetrically determined (White and Marstalerz 1966; Landis and others 1989).

Sampling

Germination was recorded for each experimental unit for 38 days after sowing and used to calculate five germination parameters: germination capacity (GC), peak value (PV), germination value (GV), germination value prime (GV'), and germination rate prime (GR'_{50}). As a measure of germination completeness, GC was calculated as the total number of germinants over the entire measured period. PV, a measure of germination speed, is the maximum value obtained using

$$PV = DCG/\text{days since start of test}$$

where DCG is the daily cumulative percent germination (Czabator 1962). GV combines germination speed and completeness calculated by

$$GV = (GC/D) * PV$$

where D is the number of days in the test. GV', a refinement of Czabator's (1962) GV, is calculated by

$$GV' = (\sum PV/N) * GC * 10$$

where N equals the number of observations used to determine PV (Djavanshir and Pourbeik 1976). GR'_{50} is equal to the number of days required for 50 percent of the seeds to germinate (Ching 1959).

Morphological measurements including height, root collar diameter (RCD), and seedling biomass were obtained from 20 seedlings at the end of the growing season (mid-November). Shoots and roots were separated and dried to a stable weight at 60 °C (140 °F) to determine seedling biomass. Shoot-to-root ratios were calculated for each seedling by dividing shoot biomass by root biomass. Sturdiness coefficients, another form of expressing the shoot-to-root relationship (Burdett and others 1984), were calculated for each seedling by dividing height (cm) by RCD (mm). Trees with lower sturdiness values signify seedlings that are more robust and less prone to mechanical damage (Scagel and others 1998).

Light

Photosynthetically active radiation (PAR) was measured for each greenhouse cover type on 11 June, 2002 between 1435 and 1456 hours. Six measurements were made in each replicate with the terminal cell of a ceptometer (Decagon Instruments, Pullman, WA). The spectral distribution of solar irradiance was measured for each greenhouse cover type and for full sun. Measurements were taken with a LI-COR 1800 spectroradiometer (from 300 to 850 nm with a spectral resolution of 2 nm). Radiation measurements were taken 10 September, 2002 between 1115 and 1135 hours. The LI-COR receptor was placed 12 cm (5 in) from the back of the growing structure between the Styroblock™ containers elevated to the height of the seedling canopies. Three measurements were made for each structure and the outside full sun.

Statistical Analysis

The general linear model of the Statistical Analysis System (SAS Institute Inc 2003) was used to analyze data. Analysis of variance and multiple comparisons, with Tukey-Kramer inequality adjustments, were completed for height, RCD, and biomass to test for fertilizer and cover type effects ($\alpha = 0.05$). Analysis of variance were completed for germination data to test for cover type effects ($\alpha = 0.05$). T-test analysis was used on PAR measurements ($\alpha = 0.05$). Assumptions for equal variances and normality were met by all data analyzed.

Results

Germination

Cover type data analysis showed the old fiberglass higher in GC, PV, GV, and GV' compared with new polycarbonate (table 2). Total germination was 9 percent higher under the old fiberglass; however, the number of days to 50 percent germination (GR'_{50}) showed no significant difference. Other indices (PV, GV, and GV') indicate a slower germination rate under the new polycarbonate greenhouse cover type.

Light, Cover, and Fertilizer Effects

New polycarbonate covers yielded a mean PAR measurement of 1014 µmol/m^2/s (standard error = 31.5), and the old fiberglass cover measured 727 µmol/m^2/s (standard error = 116.5). T-test analysis showed no significant difference at $P = 0.08$. Analysis of variance showed no significant cover x fertilizer interactions for any measured morphological characteristic. No cover effects were observed for RCD, shoot biomass, root biomass, total seedling biomass, or shoot-to-root ratio ($P > 0.18$); however, cover effects were seen in height and sturdiness coefficient ($P < 0.01$; figure 2). Significant fertilizer effects were seen for all morphological measurements with the exception of sturdiness coefficient ($P < 0.02$; table 3). Fertilizer treatments showed increased growth with increased N application. Tukey pairwise analysis detected no differences between the 40 and 60 mg N treatment rates for height, RCD, root dry weight, or shoot-to-root ratio (table 3).

Discussion

The results of Li and others (1994) showed that light has a positive effect on the germination rates and values of ponderosa pine seeds; however, this effect was not seen in this study. It was expected that germination rates and values for the new polycarbonate structure would be the same as, if not higher, than the old fiberglass structure. It is hypothesized that temperature may have been a key component in the difference of values, but unfortunately, the temperature data were lost. Therefore, we are left to speculate that more radiation, higher temperatures, and drier conditions contributed to less germination under the new polycarbonate structures. Future studies should monitor temperature and soil moisture conditions in response to elevated greenhouse temperatures, which may improve germination parameters.

Trends for increasing height, RCD, and seedling biomass in response to fertilizer treatments were expected and observed (Reed and others 1983; van den Driessche 1991). The fact that RCD, shoot biomass, root biomass, and total seedling biomass illustrated no differences between cover types

Table 2—Mean, standard error, and *P*-values for germination parameters between two greenhouse cover materials: new polycarbonate and old fiberglass ($\alpha = 0.05$).

Material	Cumulative germination	Indices of germination speed			
	GC (%)	PV	GV	GV'	GR'_{50}
New polycarbonate	75	3.2	6.5	17	12
Old fiberglass	82	4.1	9.1	24	11
Standard error	2.12	0.20	1.73	0.56	0.51
P-value	0.02	0.01	0.01	0.01	0.11

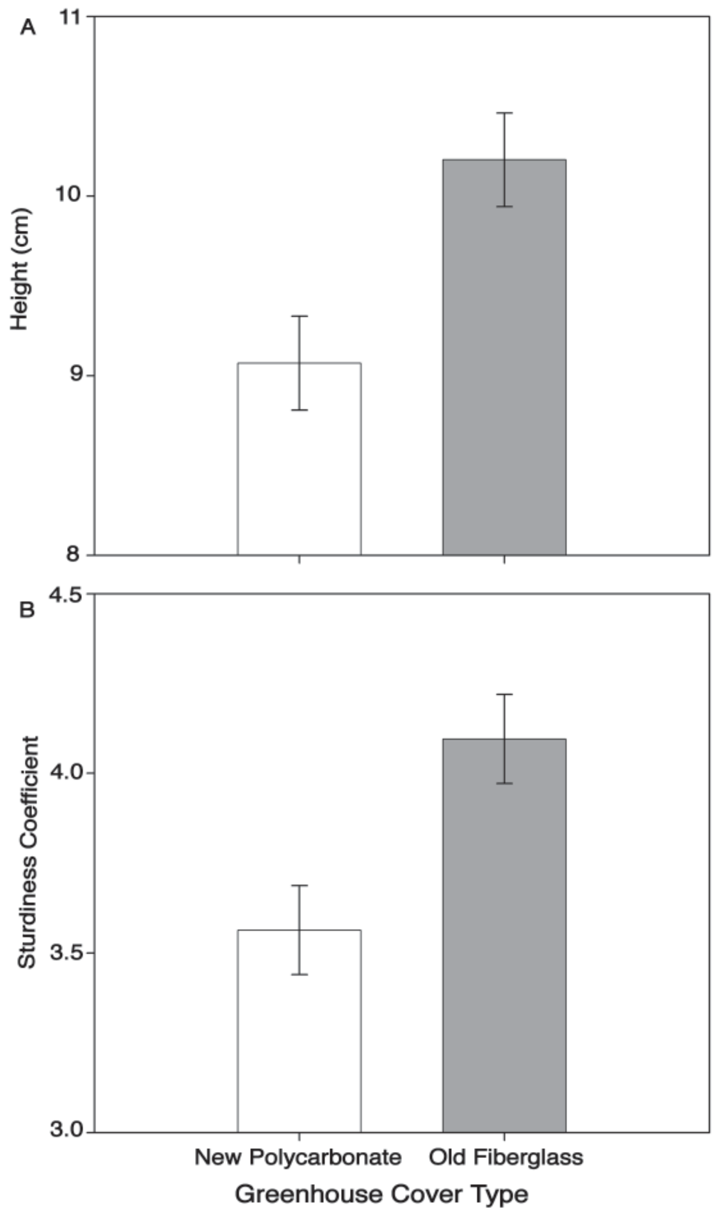

Figure 2—Seedling height (A) and sturdiness coefficient (B) under two greenhouse cover types after one growing season (bars indicate standard error).

Table 3—Mean, standard error, and *P*-values of seedling morphological characteristics under three fertilizer treatments (means with the same letters are not significantly different; α = 0.05).

Fertilizer (mg N applied per seedling)	Height	RCD	Shoot dry weight	Root dry weight	Total dry weight	Shoot-to-root ratio
	cm	*mm*	- - - - - - - -	*g*	- - - - - - - -	
20	8.44 a	2.29 a	0.60 a	0.60 a	1.20 a	1.02 a
40	9.88 b	2.59 b	0.80 b	0.69 b	1.49 b	1.18 ab
60	10.58 b	2.73 b	0.89 c	0.73 b	1.62 c	1.25 b
Standard error	0.32	0.04	0.02	0.02	0.03	0.05
P-value	<0.01	<0.01	<0.01	<0.01	<0.01	0.01

was unexpected. The spectral irradiance data shows three distinct patterns of distribution (figure 3), with the sun having the largest magnitude and the old fiberglass cover with the lowest (statistical analysis not performed), but the t-test analysis of PAR showed no statistical differences ($P = 0.08$) between cover types.

This may partly explain the lack of cover type differences seen in the morphological measurements. Although seedlings grown under the old fiberglass structures were significantly taller overall, their total seedling biomass was not significantly different from that of seedlings grown under the polycarbonate structure. From the literature, the increased height suggests that seedlings may have etiolated under the slightly lower light conditions (Bartlett and Remphrey 1998). Under the conditions of this study, it may be speculated that conditions of the growing structures did not adequately capture the differences in growth and lighting for full greenhouse environments as seen by Tuller and Peterson (1988) in Douglas-fir (*Pseudotsuga menziesii*). It may also be speculated that because the growing structures were open on one side, the nature and transmission of the cover materials may have been overcome by side light, thereby minimizing morphological differences between seedlings.

A more indepth examination of seedling biomass and shoot-to-root ratios would help to understand the relationship of etiolation and reduced light effects on seedling quality; however, due to the interaction seen in the analysis of cover type x fertilization on root biomass and shoot-to-root ratio, interpretation for this study is difficult. It is notable that at the 40 mg N fertilization rate, no difference was seen between cover types in RCD, root biomass, shoot biomass, total seedling biomass, and shoot-to-root ratio. At the 60 mg N rate, differences arise in root biomass and shoot-to-root ratio creating a seedling that may not meet target seedling quality criteria under the reduced light, old fiberglass environment. Tuller and Peterson (1988) found similar results in greenhouse-grown Douglas-fir seedlings under 4-year-old fiberglass and new polyethylene cover types. An examination of sturdiness coefficients, as a lone measure of seedling quality, shows that seedlings grown in the high light environment exhibit desirable target seedling qualities.

Summary

Although differences between cover types in this study were few, results illustrate the importance of monitoring and adjusting cultural treatments when changes occur in light intensity. In situations where greenhouses exhibit low light quality or quantity, due to an old greenhouse cover type, it is important to consider the implications of correcting for low seedling quality with increased nutrient regimes.

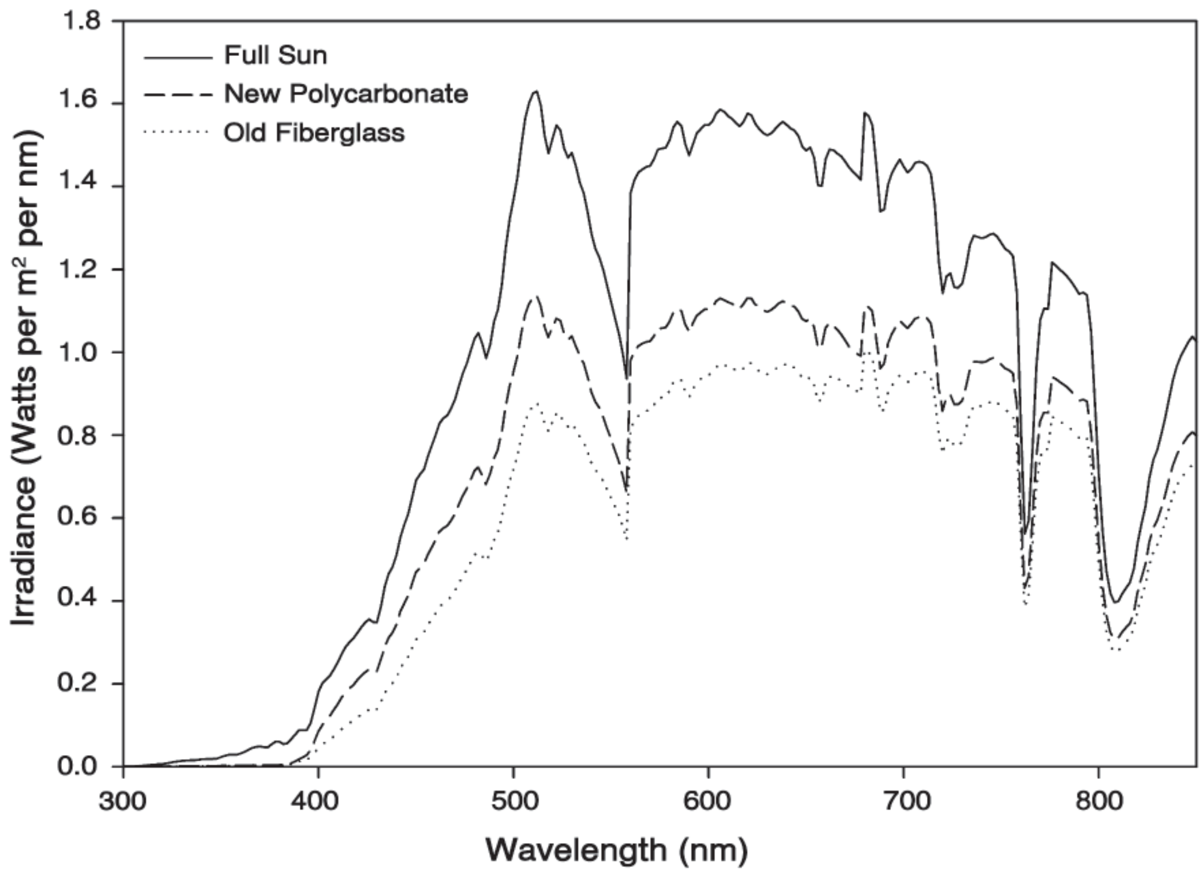

Figure 3—Spectral distribution from 300 to 850 nm of solar irradiance under full sun, new polycarbonate, and old fiberglass in Moscow, Idaho (46° 43'N, 117° 00'W), 10 September, 2002.

Conversely, under new greenhouse covers that exhibit good light quality and quantity, it is also important to consider changes in atmospheric conditions such as temperature, and adjustments to cultural applications such as nutrient regimes.

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An Evolution of Bareroot Cultural Practices at J. Herbert Stone Nursery

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Abstract: Bareroot nursery practices that maximize root development and root growth have been studied and documented over a number of years. Each nursery, however, has its own unique combination of climate, soils, species, and stocktypes for which site specific cultural practices are necessary. J. Herbert Stone Nursery, a USDA Forest Service nursery in Central Point, OR, has completed a variety of production trials to adapt general cultural practices to its site. These trials resulted in 1) developing a strategy to maintain high soil porosity through the application of organic matter and tillage measures; 2) sowing seeds earlier in the winter for 1 + 0 stocktypes; 3) lowering seedbed densities from 267 seedlings/m^2 (25 seedlings/ft^2) to between 161 and 195 seedlings/m^2 (15 and 18 seedlings/ft^2); 4) transplanting seedlings in early fall instead of spring; and 5) developing a miniplug + 1 stocktype.

Keywords: seedling culture, root volume, *Pseudotsuga menziesii, Pinus ponderosa*, root culture

Introduction

Production of planting stock with balanced shoot-to-root ratios and large, vigorous root systems to match the needs of the outplanting site is a key element in successful seedling establishment. Although reforestation sites in the Pacific Northwest are extremely variable, the characteristic most commonly shared is a long summer with little to no moisture from June through September. Seedling survival under these conditions requires rapid root growth early in the growing season to maximize water uptake and to compete with vegetation on the site. Good root development in the nursery, therefore, is important for seedling survival.

Understanding seedling root physiology, including the seasonality of root activity and growth, and the effects of nursery cultural practices on overall seedling physiology is key to improving seedling quality at a production nursery and producing a target seedling that better matches the requirements of outplanting sites (Duryea 1984). Cultural practices that can affect seedling root and shoot development include 1) soil cultivation and amendments; 2) timing of sowing; 3) seedling spacing and seedbed density; 4) timing and depth of root culturing, such as undercutting and wrenching; and 5) timing of transplanting. In addition, the continuing development of alternative, or nontraditional stocktypes can improve root morphology for differing outplanting situations.

Current Nursery Practices

Soil Management

Seedling culturing techniques, including cultivation and entire crop removal, contribute to rapid deterioration of nursery soils. Soils with a low organic content or poor soil structure have low fertility, restricted gas exchange in the rhizosphere, poor drainage, and the potential for increased vulnerability of nursery stock to pathogenic organisms (Duryea 1984). Consequently, an essential part of nursery soil management is the use of organic, and occasionally mineral, amendments. These amendments help maintain or improve soil properties, including bulk density, nutrient holding capacity, soil structure, and the environment for beneficial rhizosphere microorganisms such as nitrifying bacteria and mycorrhizae (Davey and Krause 1980).

Timing of Sowing

Determining the sowing dates for obtaining a target seedling is dependent on the soil and climate conditions of the nursery site. Spring sowing has become the norm for most western bareroot nursery operations, that is, between mid-April and early June. However, inclement weather during the relatively short sowing window may cause delays in sowing operations. Any delay in spring sowing may adversely affect seedling size at the end of the growing season, expose very young seedlings to summer seedbed heat and moisture stresses, and affect timing of dormancy in the fall. As a general rule, sowing is best done as early as possible after the average soil temperature at 10 cm (4 in) exceeds 10 °C (50 °F) (Thompson 1984).

Seedbed Density

Seedbed densities in bareroot nurseries vary widely depending on the species and stocktype. In the Pacific Northwest, densities for 2 + 0 stock can range from 161 to 323 seedlings/m^2 (15 to 30 seedlings/ft^2), with a similar range for 1 + 0 stock (Thompson 1984), although numerous studies have indicated that seedling quality, as well as plantation growth and survival, are improved by sowing seeds at lower bed densities.

Root Culturing

Cultural practices that disturb root systems to alter seedling morphology are common practice in most bareroot nurseries. Root culturing is most commonly used to stop seedling height growth, decrease shoot-to-root ratios, improve root fibrosity, and precondition seedlings for outplanting (Duryea 1984). Undercutting, or horizontal root pruning, causes a loss in apical dominance in the root system, resulting in increased lateral root growth, the development of new tertiary roots, and a more compact, fibrous root system (van Dorsser and Rook 1972), and the effects are largely influenced by the timing and depth of the pruning treatment (Riedacker 1976).

Timing of Transplanting

Seedlings can be transplanted during spring, early summer, or fall, with spring transplanting as the most common practice in the Pacific Northwest. Seedlings transplanted in spring are lifted during winter, stored for an extended period of time, and transplanted in mid- to late spring. Seedlings for early summer and fall transplanting are lifted and immediately transplanted, or transplanted following minimal storage. Spring transplanting often incurs less risk and may result in less variable survival than early summer or fall transplanting (Duryea 1984). Many nurseries, however, have succeeded in transplanting during the fall with good results (Hahn 1990).

Seedling Stocktypes

The traditional stocktypes for most bareroot conifer nurseries have included: 1) 1 + 0 seedlings that are sown directly into the seedbeds and cultured for one growing season; 2) 2 + 0 seedlings that are sown directly into the seedbeds and cultured for two growing seasons; 3) 1 + 1 seedlings which are sown directly into the seedbeds, cultured for one growing season, lifted, transplanted during the fall or spring, and grown for one additional season; and 4) P + 1 seedlings that are grown in containers for one season, extracted, transplanted in the fall or spring, and grown for one additional season. In order to shorten the growing cycle, but still produce a seedling with a well developed root system and balanced shoot-to-root ratio, production of a miniplug + 1 stocktype has been attempted at several bareroot nurseries over the past two decades with good success (Hahn 1990; Tinus 1996). The miniplug + 1 stocktype is started in small containers in the winter, transplanted in the spring, grown during the summer and fall, and lifted the following winter.

While many of these are considered well-established practices, we needed to verify or modify them for local soils, climate, stocktypes, and species.

J. Herbert Stone Nursery Trials

J. Herbert Stone Nursery is a bareroot conifer nursery, administered by the USDA Forest Service, located near Central Point, Oregon at 426 m (1397 ft) elevation. Annual precipitation averages 500 mm (20 in), with more than 90 percent occurring between mid-September and mid-May. Mean annual temperature is 12 °C (54 °F) and the growing season is 220 days (USDA 1989). Soils in the bareroot production area (approximately 86 ha [213 ac]) are deep, sandy loams formed from granitic and metamorphic alluvium. They are coarse-loamy, mixed mesic Pachic Haploxerolls classified as Central Point series. Stone Nursery was established in 1978 to meet the high demand for conifer production for reforestation of Federal lands in the western United States. The site was selected primarily for its warm climate and the potential to produce a 1 + 0 seedling.

Throughout the history of production at Stone Nursery, operational trials and studies have been implemented to improve both production and efficiency in culturing seedling crops. These studies looked at the physical environment, the physiology of various species grown at the nursery, and treatments to manipulate the morphology of seedlings to achieve target specifications. All studies were designed using randomized complete blocks with adequate buffer areas between treatments and blocks. Data sets were analyzed using SAS or similar statistical analysis programs.

Root Growth Periodicity

To gain information that would contribute to more accurate cultural prescriptions for irrigation, fertilization, and root culturing throughout the growing season, a monitoring program to determine the seasonality of root activity and growth was established during two growing seasons to collect soil temperatures, root volumes, and root activity in 1 + 0 and the first and second growing seasons for 2 + 0 Douglas-fir (*Pseudotsuga menziesii*) and ponderosa pine (*Pinus ponderosa*) seedlings.

Year 1—First year patterns of root activity and root volumes differed slightly by stocktype (1 + 0 versus first growing season for 2 + 0 stock) in Douglas-fir (figure 1). Root activity in the 1 + 0 seedlings was high at the beginning of the monitoring period in late summer, when average soil temperatures were around 17 °C (62 °F). Activity dropped off during the fall, but was rising following the occurrence of fall precipitation. Root activity in the 2 + 0 seedlings in the first growing season peaked in mid fall, when soil temperatures ranged from 13 to 16 °C (55 to 60 °F). Root volume growth showed a large increase in the first part of October, with slowing through the fall.

Root activity for both ponderosa pine stocktypes reached an initial peak in mid-October, when soil temperatures ranged from 12 to 14 °C (54 to 57 °F), with a second increase at the end of the monitoring period following initiation of fall precipitation (figure 2). Root volume increased sharply in early to mid-fall (October), with growth slowing in late fall.

Douglas-fir and ponderosa pine 1 + 0 seedlings are cultured differently than 2 + 0 seedlings during their first growing season. The 1 + 0 seedlings are sown earlier in the spring at lower seedbed densities, receive higher levels of

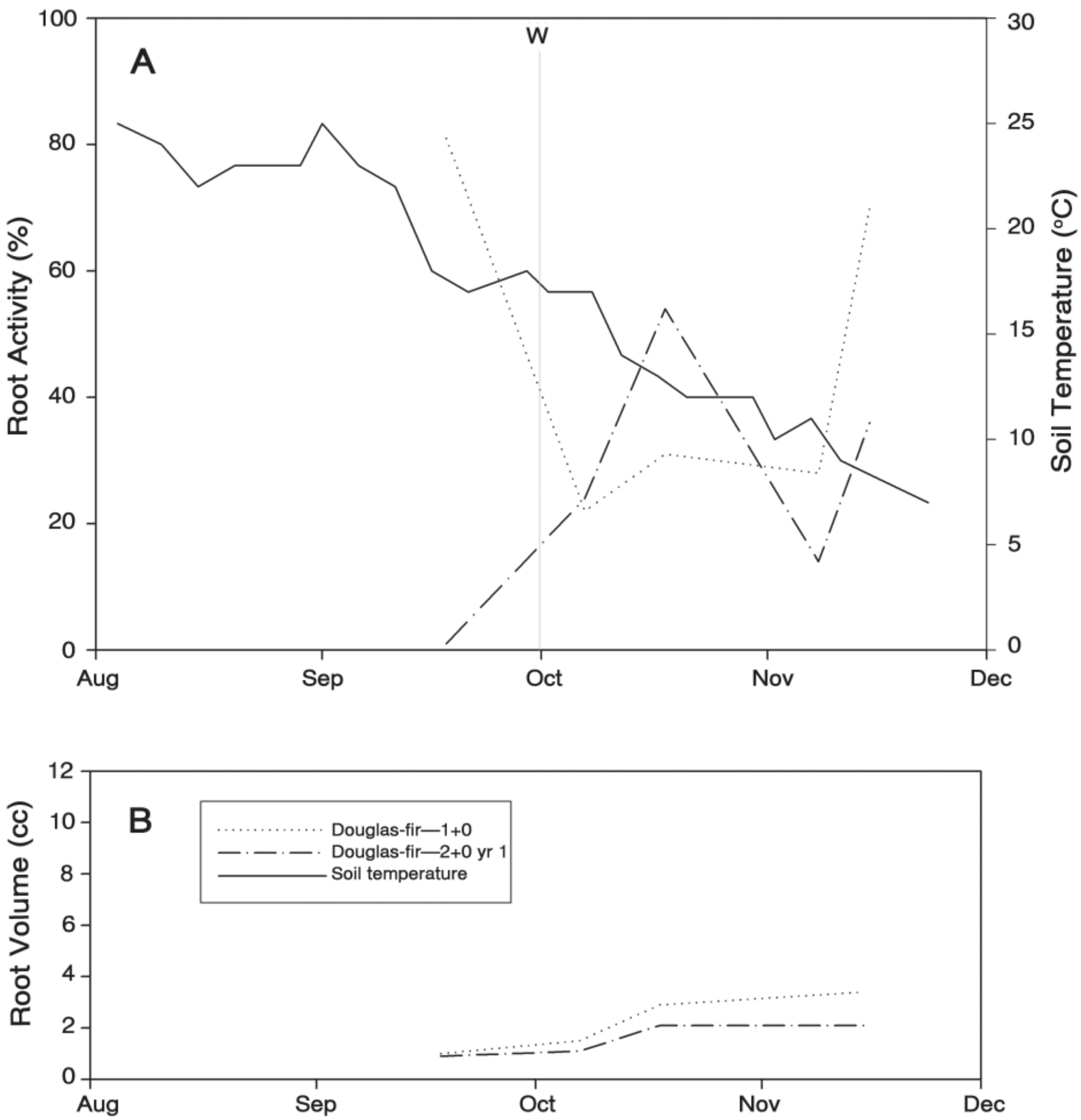

Figure 1—A) Root activity (%) and soil temperatures, and B) changes in root volume for 1+0 Douglas-fir during the fall of the 1988 growing season (W = root wrenching).

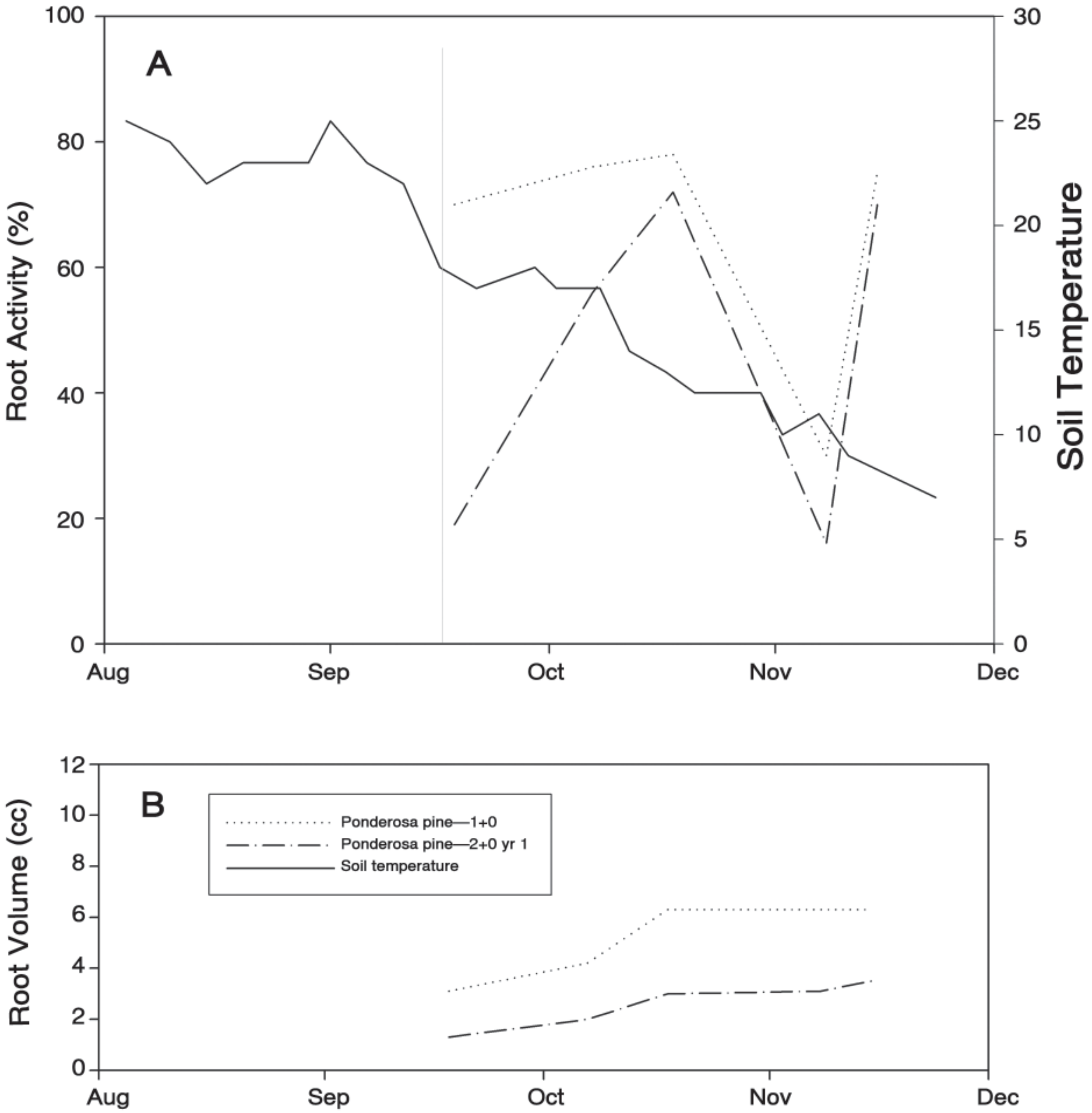

Figure 2—A) Root activity (%) and soil temperatures, and B) changes in root volume for 1+0 ponderosa pine during the fall of the 1988 growing season (W = root wrenching).

both irrigation and fertilization through mid-summer, and are subjected to dormancy induction—that is, water stress—later in the summer than seedlings grown for 2 + 0 stock. As a result, seedlings grown for 1 + 0 stocktypes are larger in both stem diameter and root volume for a more balanced, plantable seedling in the first growing season.

Year 2—Root activity during the second growing season for 2 + 0 Douglas-fir seedlings was high in early spring during both monitoring years, when soil temperatures ranged from 10 to 13 °C (50 to 55 °F). Due to competition for photosynthate, activity decreased to a low level in late spring and continued at low levels through the summer, when soil temperatures averaged around 22 °C (72 °F) but irrigation was necessary to maintain moisture in the soil profile. Activity rose rapidly in late August/early September, when temperatures decreased from 21 to 11 °C (70 to 52 °F), with several peak periods throughout the fall (figure 3). Root volume increased steadily throughout the majority of the growing season, with a large increase in volume occurring in late August through September.

Root activity in 2 + 0 ponderosa pine seedlings was high in the spring of the second growing season, with peaks occurring in late March and late April when soil temperatures ranged between 13 to 16 °C (55 to 61 °F). Irrigation was maintained and, although temperatures reached peaks of 23 °C (73 °F), root activity continued at a low to moderate level

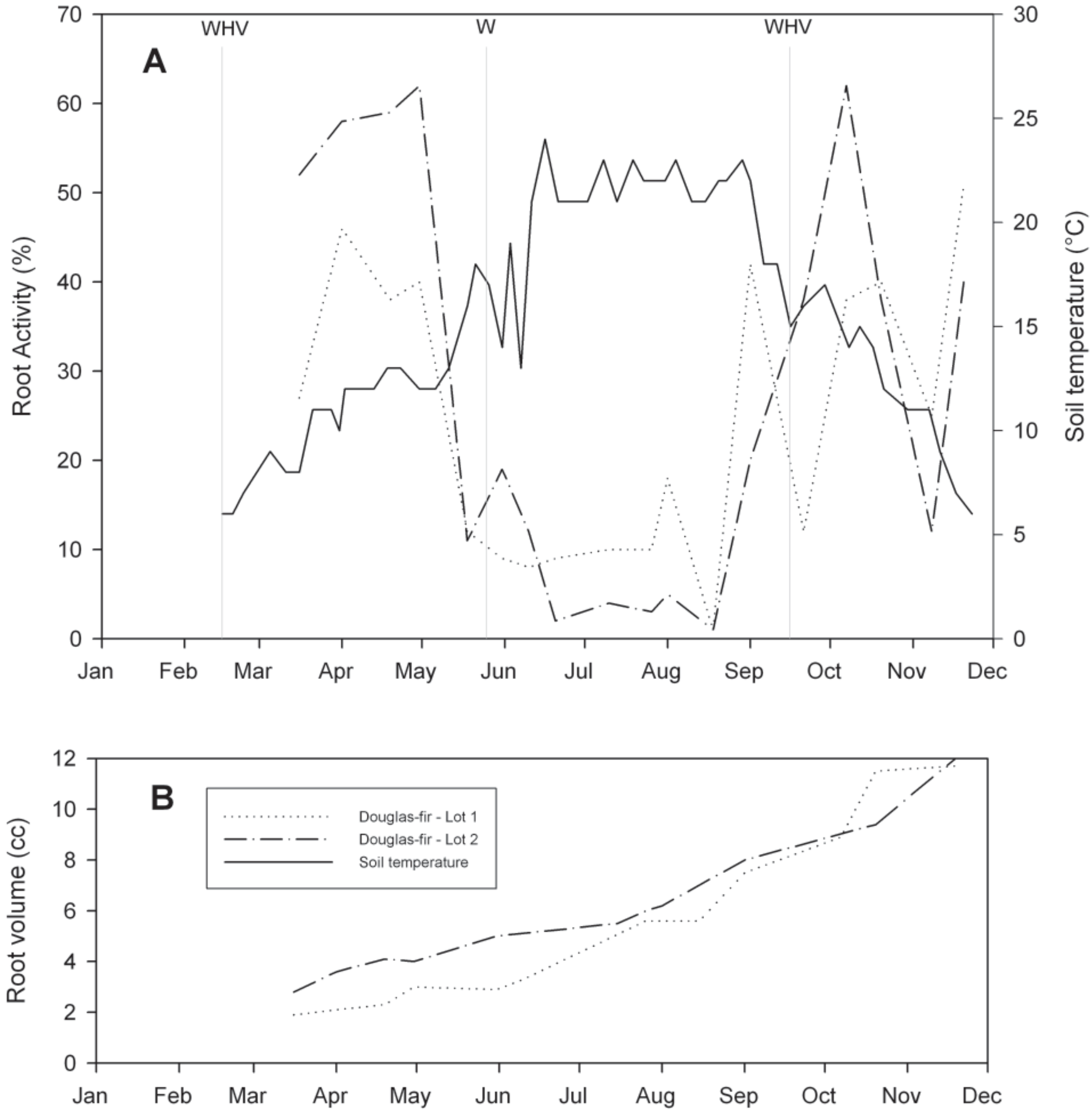

Figure 3—A) Root activity (%) and soil temperatures, and B) changes in root volume for 2+0 Douglas-fir during the course of the 1988 growing season (W = root wrenching; H = horizontal root pruning; V = vertical root pruning).

throughout the summer, with a peak in late June/early July. Activity increased in early September when soil temperatures dropped below 18 °C (64 °F), with a peak in mid-September (figure 4). Root volume showed little to no increase throughout the early part of the growing season, with a sharp increase beginning in early to mid-July. This rate of root volume growth continued through summer and into fall.

Soil Amendments

Soil management created the greatest challenge in the early years at Stone Nursery. Soils had been under agricultural crop production for over 75 years and the intensive cropping left many of the fields in a highly compacted condition and low in soil organic matter. Bulk density samples taken in 1984 were high, averaging 1.54 g/cm^3 and ranging from 1.4 to 1.8 g/cm^3. The nursery targeted 50 percent porosity for bareroot production, but average porosity was calculated at 43 percent, with a range of 34 to 49 percent. In addition, it was common to encounter an impenetrable layer 8 to 13 cm (3 to 5 in) below the soil surface once soils had dried in late spring. Soil tillage practices aimed at shattering this layer, such as ripping and plowing, only created fields full of large clods.

Over the years, Stone Nursery attempted to improve soil tilth by a variety of soil tillage practices, including multiple

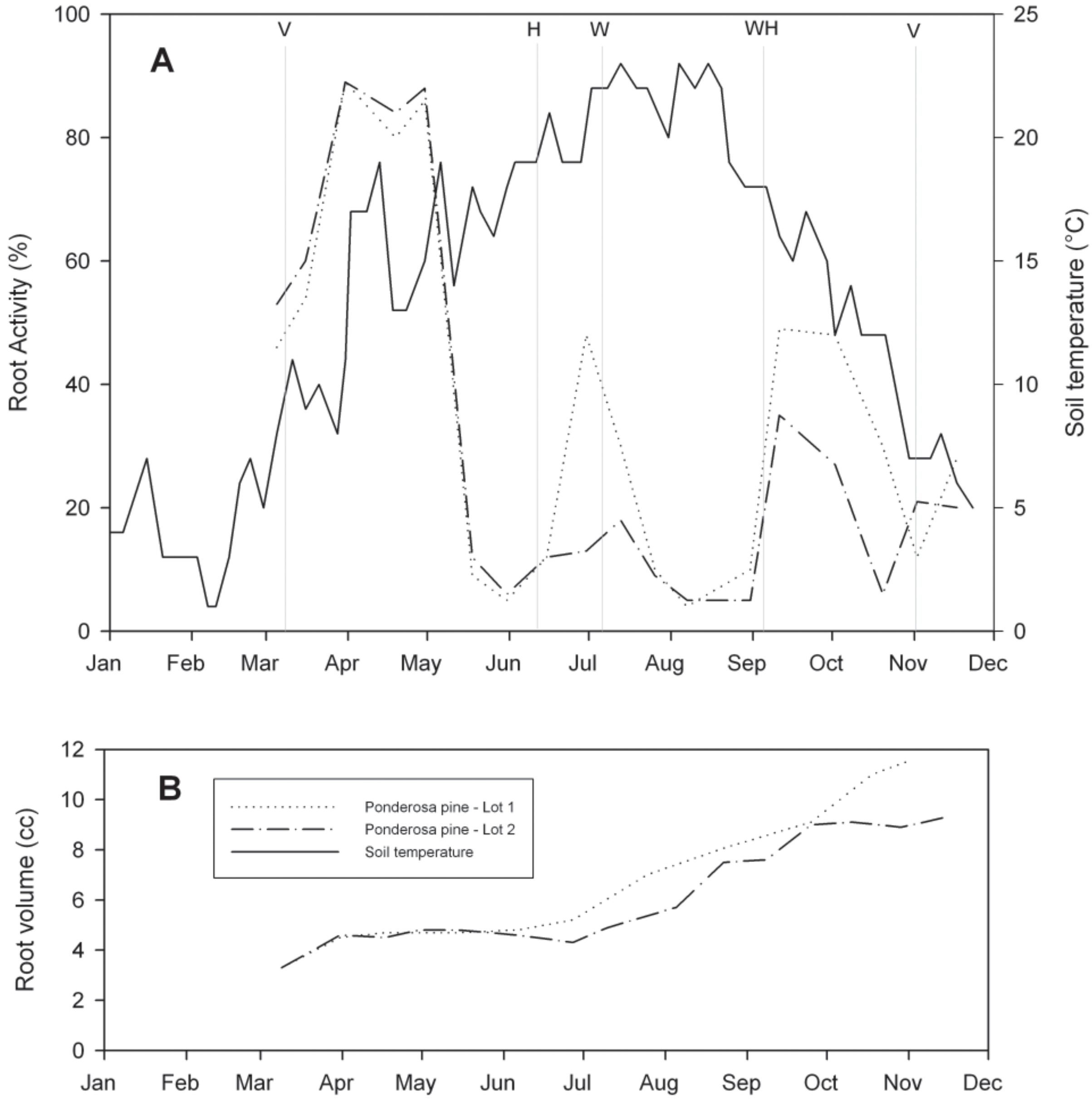

Figure **4**—A) Root activity (%) and soil temperatures, and B) changes in root volume for 2+0 ponderosa pine during the course of the 1989 growing season (W = root wrenching; H = horizontal root pruning; V = vertical root pruning).

deep subsoiling operations prior to sowing, multiple soil wrenchings following sowing, and the periodic incorporation of organic matter. Traditionally, fresh sawdust, incorporated into the soil during the fallow period between lifting of one crop and sowing of the next crop, was the preferred organic amendment. It could last for years in the soil, adding a larger and lighter component to the soil, reducing bulk density and soil strength, and avoiding the salt buildup and other contaminants of aged sawdust. The rising costs of the material and the nitrogen necessary for nutrient replacement during decomposition, however, contributed to the need to explore alternative soil amendments for seedling culture. Several amendments were tested to determine their effects on soil nutrient status, soil bulk density, and seedling morphology, including varying volumes of #6 grade pumice, which was expensive but a possible long term solution, and decomposed yard waste/sawdust mix, which was available locally at very low cost.

We observed no significant differences in bulk density or nutrient status between amendment types, even though the specific gravity of pumice is much lighter than the native soil. Although seedlings grown in soil amended with pumice showed an increase in height, there were no significant differences in root morphology and stem diameter. It appeared that standard wrenching practices, applied equally across all treatments, had more effect on bulk density and root growth than the addition of alternative soil amendments.

Timing of Sowing

One goal of the nursery is production of 1 + 0 seedlings that approach the size and have the survival potential of 2 + 0 seedlings. Prior to 1990, the target sowing date at Stone Nursery was the second week of April. Depending on the amount of seeds to be sown and weather conditions, sowing was often not completed until the middle of May. While sowing during this period produced good results, we believed that an earlier sowing date could result in several improvements. First, the longer growing season should produce larger 1 + 0 seedlings. Second, seedlings should be much larger in June and early July, and therefore more capable of withstanding *Fusarium* spp. root disease that often occurs during this period.

In order to determine if seeds sown in late winter (mid-February) could produce larger seedlings and greater seedbed survival than those sown for normal spring production, seedlots of ponderosa pine, lodgepole pine (*Pinus contorta*), Jeffrey pine (*P. jeffreyi*), and incense cedar (*Calocedrus decurrens*) were sown in late winter and again in mid-spring. Seeds were sown at standard nursery sowing densities (195 to 215 seedlings/m^2 [18 to 20 seedlings/ft^2]), cultured under standard nursery culturing regimes for 1 + 0 stocktypes, lifted in late fall, and assessed for stem diameter, height, and root volume.

Seedlings sown in late winter were larger in height and stem diameter for all species. The effect of sowing date on root volume was variable between species and among seedling lots. Significantly larger root volumes were found in incense cedar and ponderosa pine sown in late winter; root volumes for lodgepole pine and Jeffrey pine were not significantly different between sowing dates. There were no differences in survival between sowing dates.

Seedbed Density

Target sowing densities for 1 + 0 stocktypes at Stone Nursery prior to 1990 were traditionally 214 to 236 seedling/m^2 (20 to 22 seedlings/ft^2). Densities for 2 + 0 seedlings usually ranged from 236 to 267 seedling/m^2 (22 to 25 seedlings/ft^2). These densities were based on practices of other bareroot conifer nurseries in the Pacific Northwest. As production decreased at the nursery, seedbed area became available to grow seedlings at lower densities. The nursery installed several production trials to help determine the optimum seedbed density for various stocktypes and species.

1 + 0 Ponderosa Pine—Ponderosa pine seedlots, for 1 + 0 stocktypes, were sown at three densities in early spring: 107, 161, and 214 (control) seedlings/m^2 (10, 15, 20 seedlings/ft^2). Seedlings were cultured under standard nursery practices for 1 + 0 stock, lifted in late fall, and measured for stem diameter, height, root volume (Rose and others 1991), and percentage of seedlings culled—that is, those seedlings that did not meet target specifications or were mechanically damaged during the lifting process. Lowering seedbed density significantly increased seedling stem diameter and root volume, although the highest rate of mechanical damage occurred at the lowest density. There was no significant effect on seedling height.

2 + 0 Ponderosa Pine and Douglas-fir—Density and Root Pruning—Two trials were established to determine the effects of both sowing density and root culturing on survival and growth of 2 + 0 Douglas-fir and ponderosa pine. In the first trial, treatments included: 1) 214 seedlings/m^2 (20 seedlings/ft^2) seedling density and horizontal root prune at 18 cm (7 in) in mid-September (standard nursery practice; control); 2) 130 to 150 seedlings/m^2 (12 to 14 seedlings/ft^2) sowing density and 18 cm (7 in) horizontal root prune in mid-September; 3) 130 to 150 seedlings/m^2 sowing density and 10 cm (4 in) root prune in mid-August. Seedlings were lifted in mid-winter and assessed for height, stem diameter, root area, and shoot area with Machine Vision Seedling Inspection Station® equipment (Davis and Scholtes 1995).

We found no significant differences in seedling height, stem diameter, shoot area, and root area between seedbed density treatments in Douglas-fir. In contrast, the ponderosa pine showed significantly greater root area, shoot area, and stem diameter in the low density treatments as compared to the standard treatment. There were no differences between root pruning treatments.

Seedbed densities for the second trial were 107, 161, and 214 (control) seedlings/m^2 (10, 15, and 20 seedlings/ft^2). Each density treatment received two different horizontal pruning treatments: 1) horizontal root prune in mid summer (July) at 10 cm (4 in); or 2) root prune in late-summer (August) at 15 cm (6 in). Seedlings were also lifted in mid-winter and height, stem diameter, root area, and shoot area were assessed with Machine Vision Seedling Inspection Station® equipment.

Results of the second trial differed from the first in that the greatest treatment differences were in the seedbed density treatments for Douglas-fir. Root area and stem diameter increased significantly with lower seedbed density. Root pruning treatments yielded no significant differences in Douglas-fir seedling morphology, although the short root prune in mid-July killed 15 to 25 percent of the seedlings within a week of the pruning operation. The ponderosa pine seedlings had significantly larger stem diameters with reduced seedling density, but root area was significantly larger only at a density of 107 seedlings/m^2 with the early root prune treatment.

Root Culturing

In an effort to create a seedling with a more fibrous root system that is easier to pull from the ground during lifting operations and easier to root prune in the packing operations, horizontal root pruning of 2 + 0 seedlings has been done in the fall of the first growing season at a soil depth between 15 and 20 cm (6 and 8 in). Without horizontal root pruning or wrenching, taproots can grow several feet deep, making lifting very difficult. Unpruned seedlings are also difficult to prune in packing operations; taproots at 20 and 30 cm (8 and 12 in) from the cotyledon scar often have stem diameters between 3 and 6 mm. Not only is this hard on employees pruning the roots during packing, the operation leaves the seedling with a large wound.

Several production trials were established at Stone Nursery to determine if root mass could be increased by pruning earlier in the summer and at a shorter depth than the standard practice of 15 to 20 cm (6 to 8 in). The results of two trials have been discussed above. Pruning treatments alone were evaluated on 2 + 0 ponderosa pine and Douglas-fir seedlings during the summer of the second growing season. Treatments were: 1) horizontal prune at 10 cm (4 in) in early August, followed by a 15 cm (6 in) prune in mid-September; 2) horizontal prune at 10 cm in early August only; and 3) horizontal prune at 15 cm in mid-September only (standard practice). Seedlings were lifted in winter, and height, stem diameter, root area, and shoot area were measured with Machine Vision Seedling Inspection Station® equipment. No differences were found between treatments for any morphological characteristics measured.

Timing of Transplanting

Operational transplanting has taken place at the nursery, between March and early June. Due to the hot, dry climate at Stone Nursery, fall transplanting has had a low success rate. Spring transplanting, however, presents other problems. Soil moisture conditions during this period can often be very high (between field capacity and saturation), which makes proper soil preparation difficult. Transplanting under these conditions creates soils with high bulk densities and low macropore spaces immediately around the transplanted roots. The result is seedlings with poorly developed root systems. Waiting for soils to dry and become workable is the best option; however, during some years, not many days like this occur in spring.

The nursery recently re-examined fall transplanting to take advantage of drier and more workable soils, to redistribute a portion of the workload into a slower season, and to possibly increase overall seedling size as compared to those seedlings transplanted in the spring. Douglas-fir, western hemlock (*Tsuga heterophylla*), western redcedar (*Thuja plicata*), and sugar pine (*Pinus lambertiana*) seeds were sown in containers in spring and grown under greenhouse conditions. Seedlings for fall transplanting were extracted from containers and transplanted immediately into fumigated beds; seedlings for spring transplanting were hardened-off, extracted in mid-winter, freezer-stored, and transplanted in mid-spring. Seedlings from both transplanting seasons were cultured for the remainder of the year under standard nursery practices for transplants. All seedlings were lifted in winter of the following year and measured for stem diameter, height, shoot area, and root area measurements using Machine Vision Seedling Inspection Station® equipment.

Although height and stem diameter showed no significant differences among species between transplant seasons, fall transplanted seedlings produced larger root systems than those held over and transplanted in spring (Steinfeld and others 2002). There were no differences in survival for either the spring or fall transplants.

One-Year Stocktype Trials

Throughout the history of the nursery, a number of seedling stocktypes from a variety of locations and breeding zones have been grown. Traditional stocktypes have included: 1) Douglas-fir, ponderosa pine, lodgepole pine, Jeffrey pine, western larch, incense cedar, and several true firs (*Abies* spp.) for 1 + 0 stock; 2) Douglas-fir, ponderosa pine, lodgepole pine, Jeffrey pine, sugar pine, western white pine (*Pinus monticola*), incense cedar, western redcedar, western hemlock, Engelmann spruce (*Picea engelmannii*, and several true firs for 2 + 0 stock; 3) Pacific silver fir (*Abies amabilis*) for 3 + 0 stock; and 4) Douglas-fir and ponderosa pine for 1 + 1 stock.

With the uncertainty of wildfires, site preparation, and budget projections impacting planning and timing of outplanting, Stone Nursery felt that producing a well balanced, miniplug transplant in 1 year would be of great interest to many clients. In an effort to compare the traditional 1 + 0 stocktype with the development of seedlings produced with this newer plug technology, three Douglas-fir stocktypes were tested: 1) 1 + 0; 2) miniplug + 1 (Jiffy-Pots™ [28mm in length]); and 3) miniplug + 1 (Styroblock™ 2A containers—40 cm^3 [2.4 in^3]). Seeds were sown in Jiffy-Pots™ and Styroblock™ containers in late winter and grown under greenhouse conditions. Seeds for 1 + 0 seedlings were field-sown in mid-spring. Seedlings produced in Jiffy-Pots™ were transplanted in mid-spring, as the roots and medium were held together with netting. Seedlings in Styroblock™ 2A containers were held for transplanting until early summer in order to develop a root system that would hold the medium together during seedling extraction. All seedlings were grown for 9 months, lifted the following winter, and measured for height, stem diameter, root area, and shoot area using Machine Vision Seedling Inspection Station® equipment. The resulting miniplug + 1 seedlings from both container types had greater root area and stem diameter, and lower shoot-to-root ratios, than seedlings grown under standard 1 + 0 stocktype culture.

Management Implications

The nursery trials conducted over the past two decades have allowed the nursery to refine cultural practices based on the physiological responses of the species to local site conditions and different culturing techniques. In the mid-1980s, the nursery changed its philosophy about summer irrigation. Instead of allowing soils to remain dry throughout the summer, the soil profile was irrigated to 30 cm (12 in) when pre-dawn plant moisture stress approached –1.2 MPa (–12 atm). Nursery personnel believed that root volume growth occurred in summer and fall and that moisture during these periods was critical for developing a good root system. Root activity monitoring initiated 3 years after this change supported this decision, as this was the time of year when seedlings were putting on some of their greatest growth. Because high rates of irrigation in summer created a problem of shoot growth exceeding target height specifications, it became common practice to root wrench after most soil profile irrigations. Wrenching created a slight seedling stress, causing slowing of top growth or, if seedlings had set a bud, to prevent budbreak. In addition, the results of root monitoring helped the nursery schedule the timing of second-year nitrogen applications; fertilization now occurs during the peak root activity period in early spring to maximize nutrient uptake.

Soil management practices at the nursery have remained unchanged, with fresh sawdust remaining the amendment of choice. Although many of the standard culturing practices employed at the nursery overwhelm the short-term benefits of applying a soil amendment, these amendments, especially organic amendments, are important. Pumice would possibly provide a long-term benefit, but sawdust or some form of organic matter remains necessary to maintain or raise the organic matter of the nursery soil. The locally available mulch was simply too variable. Since this trial, the nursery has approached the application of a new soil amendment from a short- and long-term standpoint. Any negative effects of the amendment on seedling growth in the first year after application, and the effects on long-term soil productivity, must be determined.

Timing of sowing has changed. Sowing is now done as early in March as possible, during breaks in the weather, when soils become dry enough to form seedbeds. Germinants from early sown seedbeds usually emerge by late March through early April. Although there is a risk of frost damage from low temperatures during this period, frost protection has not been necessary since sowing dates were moved into the late winter.

Seedbed densities of all 1 + 0 species have been lowered from 236 to 161 seedlings/m^2 (22 to 15 seedlings/ft^2). The standard 2 + 0 sowing density of 236 to 267 seedlings/m^2 (22 to 25 seedlings/ft^2) has been reduced to 194 seedlings/m^2 (18 seedlings/ft^2). Economics play a large role in determining optimal seedbed densities for any particular stocktype. More land under production equates to increased hours of tractor operation, increased labor costs, and increased weed control costs. A balance must be found between these costs and the increases in revenue from higher numbers of shippable seedlings. The nursery is considering reducing densities in 2 + 0 stocktypes further, but needs to determine if the benefits outweigh the increased costs associated with placing more land in production.

Little gain, and far more risk, has been found in either shortening the depth of the horizontal root prune or pruning earlier in the summer of the 1 + 0 year. Pruning earlier at a shorter depth increases the risk of seedling mortality and stress. Accomplishing a 10-cm (4-in) root prune in the soils at Stone Nursery is actually very difficult due to the tendency to pull the outside row of seedlings to the surface. Future work at the nursery will look at the possibility of accomplishing the root pruning objectives with several summer wrenching operations in the first growing season or eliminating root pruning entirely.

A portion of transplanting has been shifted to fall. Stone Nursery now begins transplanting container seedlings as early as the first week of September to take advantage of the warm September soil temperatures for greater root growth. In the past 6 years, transplanting in the fall has produced a more balanced, larger seedling at reduced costs, while allowing the nursery more flexibility in managing the work force and equipment.

In exploring the possibilities of new stocktypes, the nursery has demonstrated a potential to produce a seedling with a large root mass and well balanced shoot-to-root ratio in 1 year. In 2002, a transplant system was developed to apply these findings operationally. Based around the Q Plug™, which is a plug that holds together independently of root development, a program of growing seedlings for 10 weeks in Q Plugs™ under greenhouse conditions, transplanting into bareroot beds in early spring, growing for 9 months, and lifting during the winter has been established (Steinfeld 2004). New transplant equipment developed for this container allows for exact spacing of seedlings and optimum seedling density control. Economically, this stocktype has lower culling rates and more crop uniformity, resulting in an increase in revenue from higher numbers of shippable seedlings. Morphologically, the result is a well-balanced seedling with a well-developed root system available approximately 1 year following placement of seedling orders.

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Panel Discussion: Stocktypes for Outplanting in Zion National Park

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Keywords: exotic species, native species, restoration, native plant nursery

Introduction

Zion National Park is located in southwestern Utah at the junction of three geographic regions: the Mojave Desert, the Great Basin, and the Colorado Plateau. This unique geography creates distinctive habitats in Zion. With the Virgin River running through the middle of the park, Zion is a refuge for plants, animals, and humans as well.

You would think that restoration with native plants in their native habitat would be a simple job, particularly inside an agency without multiple use issues to contend with. But there are three major variables to contend with on every revegetation project. These obstacles have directed the Zion Vegetation staff towards specific stocktypes for successful outplanting of native vegetation grown at the Zion Native Plant Nursery.

Annual Precipitation

Zion's average annual precipitation is 15 in (38 cm). Unfortunately, this is not a reliable number. In 2002, at 4.8 in (12.3 cm), Zion had the lowest rainfall on record. In 2005, the highest rainfall on record occurred, more than 31 in (79 cm) (table 1). Due to staffing levels, supplemental water is next to impossible, so the highly unreliable moisture levels make revegetation with container stock problematic.

Annual Exotics

Riparian corridors are diverse, dynamic, and complex biophysical habitats that are especially critical in the arid regions of the southwestern U.S. Because these areas are literally oases in the desert, they attracted Euro-American settlers who took advantage of the relief and resources found there. Often, subsistence farming activities took place near riparian areas where water conveyance was made possible for irrigated crops. Unfortunately, this type of historic high intensity land and water use introduced many exotic plant species that, over time, have degraded these fragile ecosystems.

In what is now Zion National Park, centuries of grazing and farming combined with several years of drought have allowed exotics to invade and predominate in the Virgin River corridor. Approximately 70 percent of the canyon floor is currently infested with aggressive exotic annuals, predominately brome grasses (*Bromus tectorum* and *B. diandrus*) (figure 1).

Table 1—Annual precipitation for Zion National Park in recent years (water year runs from October to September).

Year	Rainfall (inches)[a]	
1999	13.0	
2000	9.0	
2001	13.5	
2002	**4.8**	Lowest on record
2003	14.1	
2004	12.5	
2005 to 10 Sept	**31.2**	Highest on record

[a] 1 in = 25.4 mm

Figure 1—Single native plant (prickly poppy [*Argemone munita*]) surrounded by a field of *Bromus diandrus.*

These annual exotics are able to out-compete the native vegetation, especially during drought years, by germinating early and depleting available soil moisture. When conditions are not favorable to brome grasses, or even when park staff are able to control the bromes through fire, manual, or chemical means, different annual exotics often invade by taking advantage of the resulting open space and disturbance.

Annual Visitation

Visitation in Zion National Park has more than doubled over the past 15 years to a record 2.7 million in 2004. This dramatic increase initiated development of the Zion Canyon shuttle system that operates from the end of March through October—Zion's busiest months. Prior to operation of the shuttle system, visitation in the main canyon was restricted to the limited number of available parking spaces. While the shuttle allows more public access to the most popular sites in Zion Canyon, it has also concentrated use around the seven shuttle stops within the canyon. This has resulted in heavy off-trail use in many areas. When just a few people travel off-trail to form a "social trail," others often follow thinking that "it must be OK if other people are doing it," or "there must be something interesting over there." This often leads to severely eroded sites and trail damage (figure 2).

To mitigate this damage, the vegetation staff uses a variety of techniques including fencing, ropes and stakes, a "stick to the trail" campaign complete with stickers for children, and a variety of signs (figure 3). Our "Restoration Area—Please Stay Off" is the most effective sign in use, but

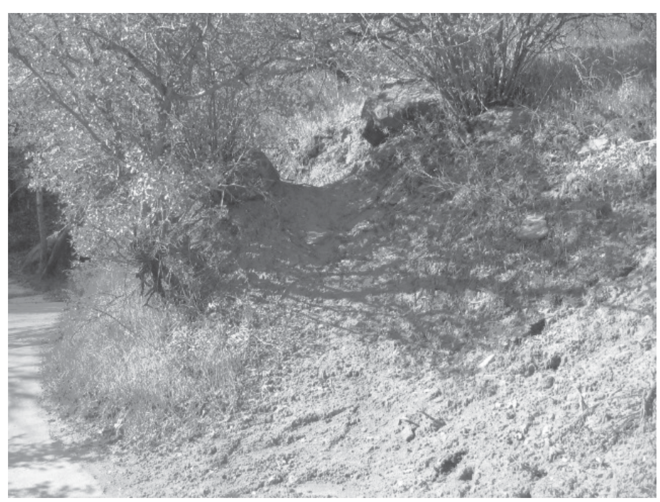

Figure 2—Damage and erosion caused by heavy off-trail use by visitors.

Figure 3—Attempts at the “stick to the trail” campaign to keep visitors out of fragile areas and to avoid off-trail use.

it only works in conjunction with plantings that are very obvious to the visitor. Trampling by visitors is not usually deliberate, but the signs clearly let visitors know that restoration work has occurred and that the plants are fragile and should not be stepped on.

Restoration in Zion National Park ___

Plant Requirements

For *all* of the aforementioned restoration obstacles, the vegetation staff at Zion has learned that bigger plants with deep roots are much more conducive to establishment for a number of reasons.

1) The well developed, deeper roots help the plants survive low precipitation years by utilizing the cooler and moister soil beneath the very hot, dry surfaces in the canyon. (Daytime temperatures in the summer months are often more than 110 °F [43 °C]).

2) Larger plants fare better when competing with annual exotics for moisture and sunlight—the roots reach deeper into the soil profile and the leaves are less likely to be shaded by the fast-growing annuals.

3) Larger plants are more obvious to the visitors in conjunction with signs and are far less likely to be trampled.

Container Types

Because desert plants are usually deeper rooted than plants from other regions, the Zion Native Plant Nursery uses narrow, deep pots of various sizes for most of their nonriparian plants.

1) D40 Deepots™ Cells (2.5 in [6.4 cm] wide by 10 in [25.4 cm] deep, or 40 in^3 [656 cm^3]) are used for grasses, forbs, and some shrubs (figure 4). In addition to producing deep-rooted plants, this system has the additional benefit of removable cells that allows for better spacing once plants are mature.

2) Tall One Treepots™ (4 in [10 cm] wide by 14 in [35.6 cm] deep, or 173 in^3 [2.43 l]) are used for most shrubs (figure 5).

3) TPOT8 Treepots™ (11 in [28 cm] wide by 24 in [61 cm] deep, or 1,848 in^3 [30.3 l]) are the containers of choice for nonriparian trees. However, benefits to tree establishment must be balanced with the additional labor required to dig holes big enough to plant trees of this size. An auger can drill adequate holes, but it must be transported to the site and operated by trained personnel (figure 6). Because most of Zion's outplanting is done by volunteers, outplanting with an auger is usually not feasible. For this reason, trees are often grown in TPOT2 Treepots™ (6 in [15 cm] wide by 16 in [41 cm] deep, or 380 in^3 [6.3 l]) or TPOT4 Treepots™ (7.75 in [20 cm] wide by 18 in [46 cm] deep, or 588 in^3 [9.6 l])

Because these pots are black and absorb radiant heat from the sun, which can overheat the rootzone, the pots placed in full sun for most of the summer are painted white by volunteers. Individual pots may be painted or larger pots that contain many pots may be painted (figure 7).

Outplanting

When outplanting, establishment has been enhanced by planting into a pocket slightly deeper than the soil surface—this helps funnel moisture to the root zone. We also mulch with wood chips (usually cottonwood) produced from fuel reduction projects near developed areas. This helps to prevent soil surface moisture loss.

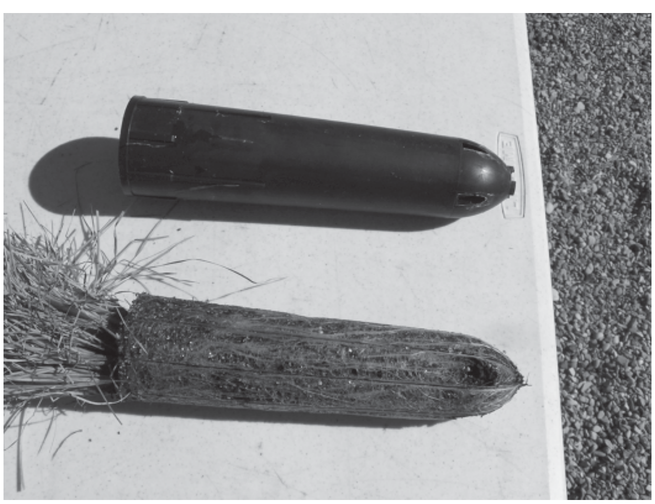

Figure 4—D40 Deepots™ are used for grasses, forbs, and some shrubs.

Figure 5—Tall One Treepots™ are used for most shrubs.

Figure 6—Planting auger necessary for outplanting stock grown in large containers.

Figure 7—Individual pots or pots containing many pots painted white to reduce heat stress.

Projects

Not all of Zion's restoration projects are in arid environments. The Colorado Plateau is famous for hanging gardens where specialized moisture-loving flora and fauna live on wet walls and floors. Hanging gardens are formed when subsurface water contacts an impermeable geologic layer and seeps from vertical sandstone walls. This results in two specialized habitats: the wall itself and the wet floor below. In Zion, numerous hanging gardens are being degraded by an exponential increase in visitation. Riverside Walk, the most heavily used trail in the park and gateway to the famous Narrows hike, passes alongside several hanging gardens. The Riverside Walk trail can receive over 3,500 visitors each day between April and October. The Hanging Gardens there are cool, moist, and inviting in summer months when temperatures often exceed 100 °F (38 °C); as a result these unique places are subjected to the most concentrated visitation levels. Many of the garden floors are now denuded and the soil is heavily compacted by excessive trampling (figure 8). Additionally, these poor conditions have led to invasion of nonnative plants in and around the gardens resulting in degraded endemic animal habitat and ecological function.

Thanks to a recent grant, Zion is currently working to restore some of these heavily visited hanging gardens. An interpretive sign is being developed, and some of the hanging garden floors have been fenced along the Riverside Walk trail. Rhizome cuttings of species that occur on both the walls and floor (maidenhair fern [*Adiantum pedatum*], cardinal monkey flower [*Mimulus cardinalis*], and Jones' reedgrass [*Calamagrostis scopulurum*]) were taken from the hanging garden walls in February and placed into 4-in (10-cm) by 14-in (36-cm) by 20-in (51-cm) Dyna-flats™ (figure 9). These were grown in a shadehouse through the summer and will be cut into approximately 4-in (10-cm) "brownies" and planted into the wet hanging garden floors in the fall. With the fencing preventing trampling by visitors and plenty of water due to the seeping walls, the plants will thrive and should fill in the degraded areas in a relatively short period of time.

Figure 8—Damage to Hanging Gardens due to overuse in the summer months.

Figure 9—Maidenhair fern cuttings grown in Dyna-flats™.

Summary

The majority of revegetation and restoration occurs in the more arid and overused habitats of Zion National Park. After several years of trials to determine the best ways to overcome restoration obstacles, Park vegetation staff have learned a number of lessons to aid in plant establishment, including: 1) grow plants with well-developed, deep roots; 2) grow plants as large as are feasible to outplant to combat trampling; 3) plant deep, that is, deeper than the soil surface and preferably in pockets to collect moisture; 4) mulch wherever possible; and 5) prevent trampling wherever possible.

Panel Discussion: Container Stock and Why?

Randy Friedlander

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Abstract: The Colville Confederated Tribes Nursery grows conifers, native shrubs and grasses, and root and stem cuttings in three cavity sizes of Styroblock™ containers, including 5.5, 10, and 20.5 in^3 (90, 164, and 336 cm^3). The choice of container size is based on client request and the requirements of the outplanting sites.

Keywords: target seedling, stocktypes, cavity size, native species

Terminology

Understanding terminology in container stock and how particular stocktypes are used is an important first step in communication between the grower and the clients. Foresters and planters tend to refer to container size in terms of cubic inches per cavity; greenhouse operators and culturists refer to container systems in terms of the number of cavities per block and/or cavities and milliliters per cavity. For example, a container system referred to as a 77/170 is the same as a 10 in^3 (164 cm^3) cell system.

Colville Confederated Tribes Nursery Practices

The Colville Confederated Tribes Nursery, located in Nespelem, WA, is a small nursery with a capacity of 3 million seedlings, although there are approximately 2 million seedlings currently being grown at the facility. The nursery serves the Confederated Tribes of the Colville Reservation Forestry Districts. These districts comprise approximately 1.4 million ac (567,000 ha) and are the sole clients of the nursery.

Container Types

The nursery uses three sizes of Styroblock™ containers for their container systems. The choice of container depends on the requirements of the outplanting sites. Bareroot seedlings are also outplanted on tribal lands, but these seedlings are purchased from other growers.

Seedlings are grown in 5.5, 10, and 20.5 in^3 (90, 164, and 336 cm^3) or 160/90, 77/170, 45/340 Styroblock™ containers, with different target specifications for each species (tables 1 and 2). Specifications have been determined based on the outplanting needs of the Forestry Districts.

Table 1—Seedling specifications by container for western larch *(Larix occidentalis*) and Engelmann spruce (*Picea engelmannii*) (root length is constrained by container length).

Container size	Caliper target	Height target	Root length
in^3	*mm*	--------- *in* --------	
5.5	3.0	8.0	6
10	4.0	9.8	6
20.5	5.0	11.8	6

Table 2—Seedling specifications by container for ponderosa pine (*Pinus ponderosa*) and lodgepole pine (*Pinus contorta*) (root length is constrained by container length).

Container size	Caliper target	Height target	Root length
in^3	*mm*	--------- *in* --------	
5.5	3.0	6.0	6
10	3.5	6.5	6
20.5	5.0	7.0	6

Styroblock™ containers are the system of choice at the nursery for a number of reasons: 1) they are readily available; 2) the blocks work well with automated sowing equipment; 3) blocks are easy to handle; and 4) large quantities of Styroblock™ seedlings are easy to package and transport to outplanting sites in small vehicles. The latter is a big advantage with very limited forestry staffing, because it is necessary to place as many trees in boxes and as many boxes on small trailers or in vehicles as possible.

Sowing

Styroblock™ containers are automatically filled with a flat filler (figure 1). A conveyor belt brings medium from the outside to a holding bin; the medium then drops into the blocks loaded onto the filler. Filled blocks are fed into a drum seeder that automatically drops seeds into cells at a rate of 1, 2, or 3 seeds per cell, depending on germination rates (figure 2). The drum seeder works directly off air pressure and suction and is specifically adjusted for container size, which is an additional reason for using only three container sizes. Following sowing, grit is applied mechanically and seeds receive an initial watering.

Lifting and Packing

Lifting and packing are both manual processes. Blocks are conveyed to a central packaging line where 6 to 12 people pull seedlings from containers by hand and package them into plastic bags. One person packages the bags into boxes, which are then placed in cold storage.

Seedling Production

Plug size is based on customer outplanting needs. The larger containers (20.5 in^3 [336 cm^3]) are recommended for drier sites where larger root masses are required. If cost is an issue, seedlings are often grown in smaller containers (5.5 in^3 [90 cm^3]), with the option of transplanting with another grower. Although container seedlings do not have as much root mass as bareroot seedlings, the 10 and 20.5 in^3 containers yield sizeable plugs that are similar in mass (figure 3).

The nursery grows conifers, native shrubs, and native grasses from seeds, as well as cuttings from both roots and stems (figures 4 and 5), in containers. Currently, the nursery is working with the Department of Fish and Wildlife to grow bitterbrush (*Purshia tridentata*) (figure 6) and grass plugs for rangeland and fire rehabilitation.

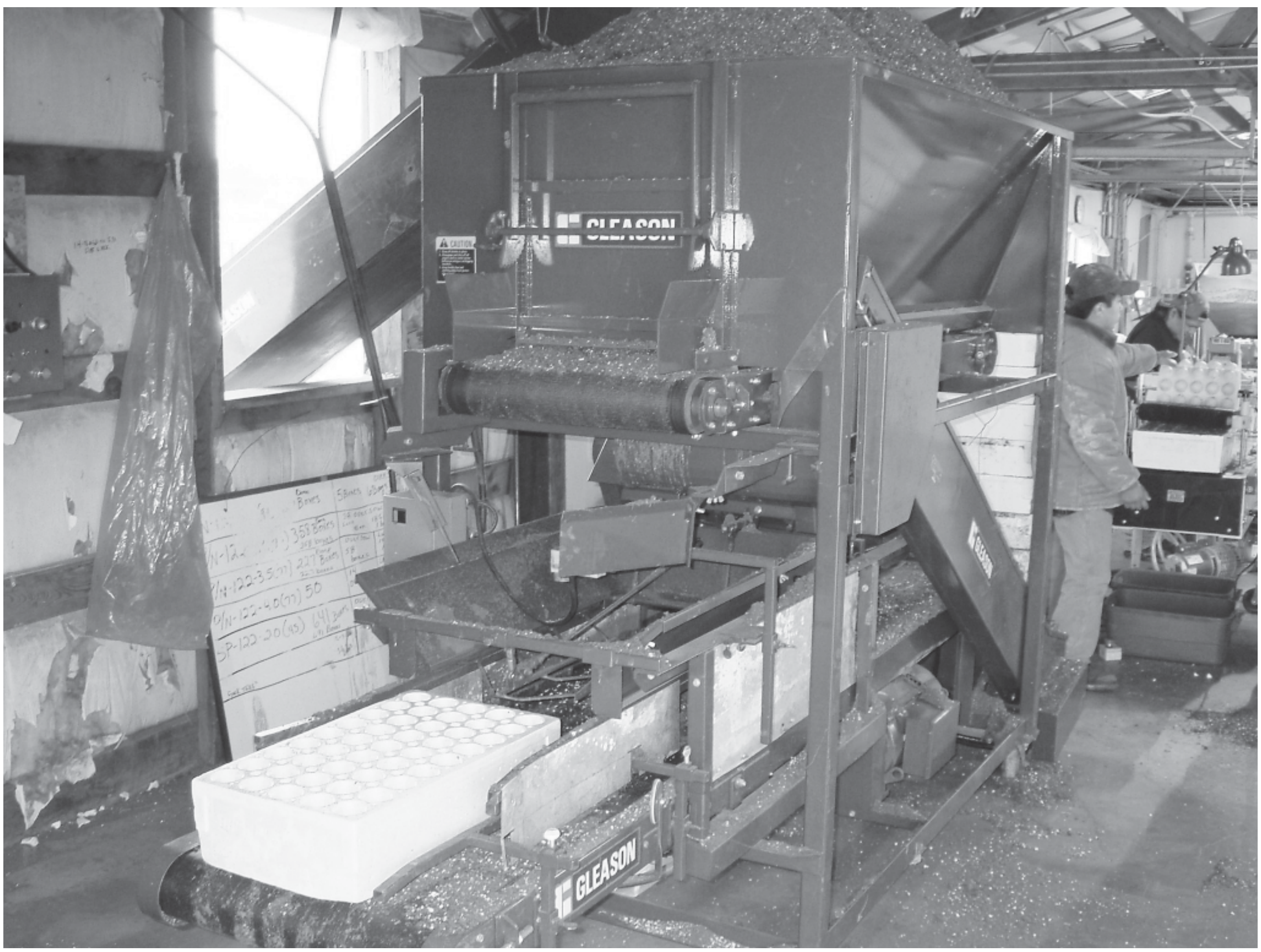

Figure 1—Flat filler automatically fills Styroblock™ containers with medium.

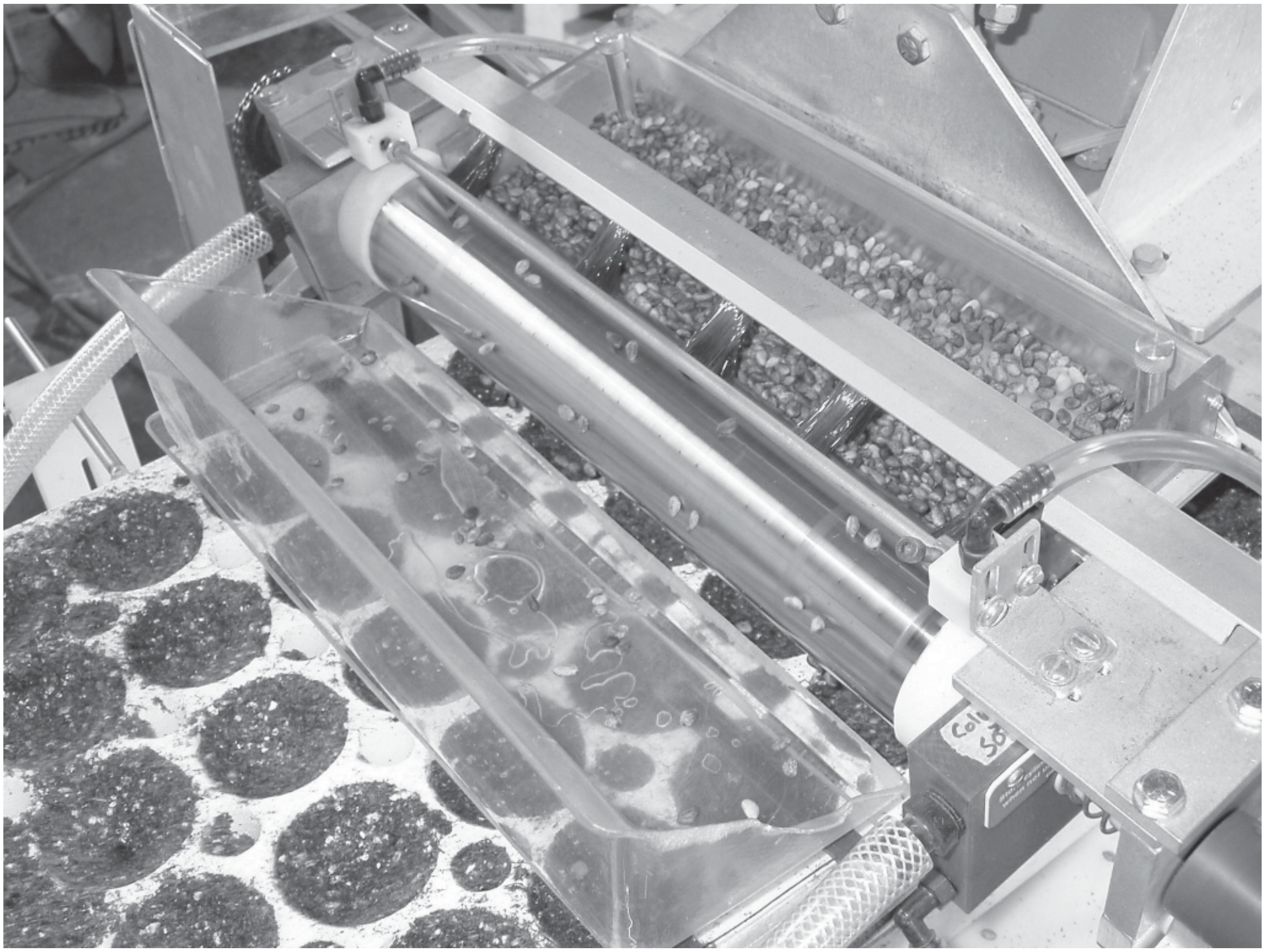

Figure 2—A drum seeder automatically drops seeds into each cell at a rate dependent on germination.

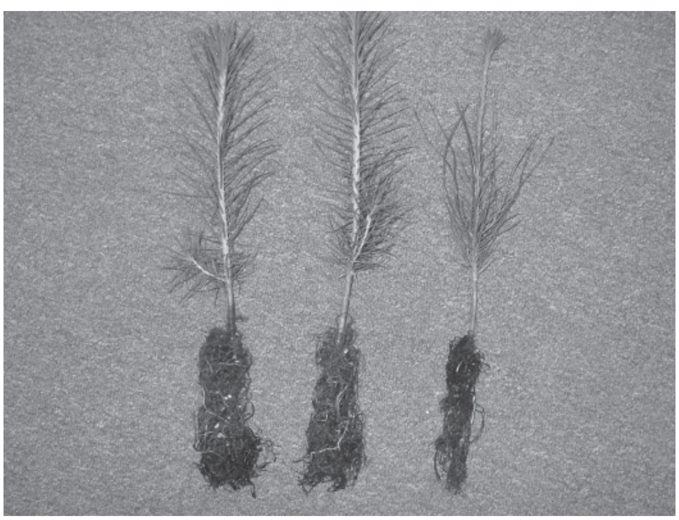

Figure 3—The 10 and 20.5 in^3 (77/170, 45/340) Styroblock™ containers yield a similar root mass at the end of the growing season.

Figure 4—Chokecherry (*Prunus virginiana*) grown from root cuttings.

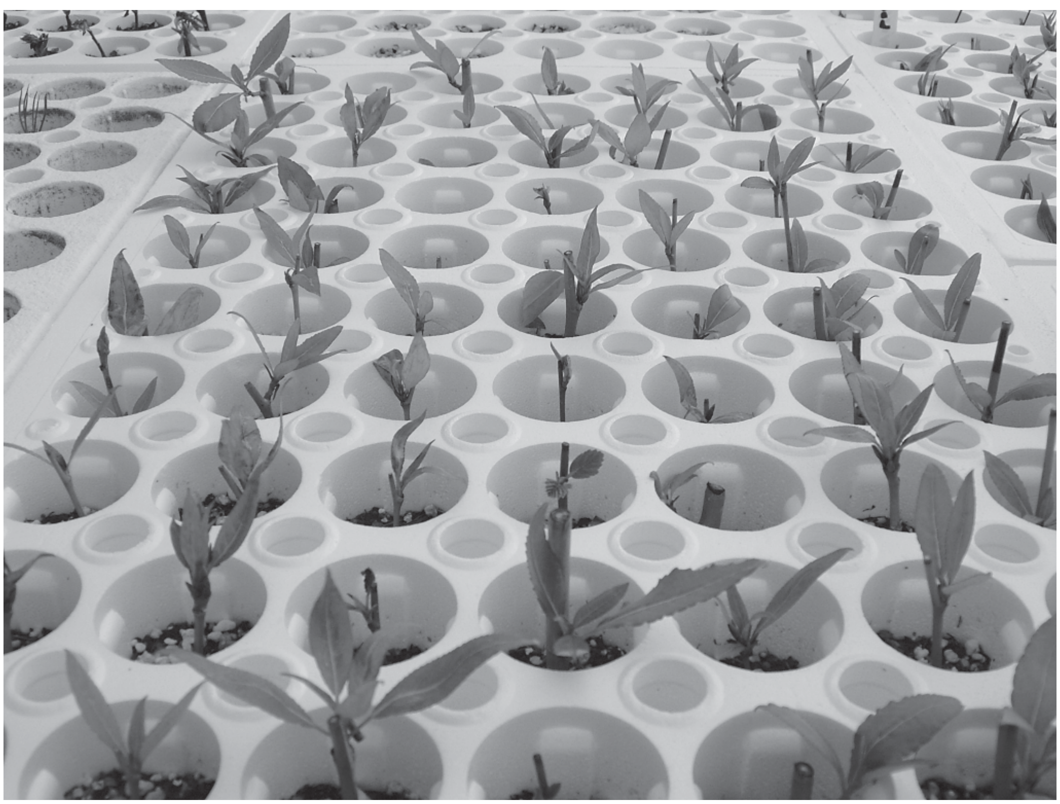

Figure 5—Black cottonwood (*Populus trichocarpa*) grown from stem cuttings.

Figure 6—Bitterbrush grown from seeds.

Panel Discussion: Trends in Container Types

Eric Stuewe

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Abstract: Container types and sizes vary depending on the requirements of the target seedling and the nursery culturing regime. Containers designed specifically for root pruning are available, as well as different types, sizes, and shapes for various species and objectives. With more options accessible to the grower, container use has changed over time.

Keywords: root pruning, container size, subirrigation

Introduction

Constantly changing nursery growing regimes and the culturing of increasing numbers of native species have required container manufacturers and vendors to provide a wider variety of propagating containers and individual pots. An overview of some of the new concepts in container seedling production and recent trends in seedling containers and pots are presented below.

Container Types

Root Altering Methods

Both air and chemical root pruning have been used to enhance lateral root development along the entire root ball in many species.

Air Root Pruning—Plastic containers with side slits on the vertical side of the cavities are most commonly used for air pruning. These slits provide a lateral location for pruning, creating many lateral roots up and down the vertical side of the plug (figure 1). A recent innovation in this system is to block off the side slits on one side of the perimeter trays of the growing area to help prevent the excessive dry down of the outside row of cavities.

Chemical Pruning—Coating cavities or pots with a copper coating material has become a popular method to chemically prune roots at the cavity wall. The copper coating will prune the roots as they come in contact with the cavity wall, thus creating more lateral roots at the point of pruning. When copper coating is used, the root tips will form throughout the length of the tube (figure 2). Roots in uncoated containers will form down the sides with the tips emerging at the bottom drain hole.

Copper-Treated Ground Cloth—Ground cloth fabric permeated with copper will prune roots protruding from the bottom drain holes of seedling cavities when the containers are placed in direct contact with the ground (figure 3).

Plug-In-Plug

The plug-in-plug growing concept involves growing seedlings for 6 to 12 weeks in small cavities and transplanting into much larger plugs to complete their growth during the next 8 to 12 months (figures 4a and 4b). The use of polymer plugs is popular for the smaller plugs, since transplanting can take place prior to full root development.

Figure 1—Containers with vertical side slits enable the air pruning of lateral roots.

Figure 2—Seedling produced in a copper-treated cavity with good lateral root formation.

Figure 3—Bottom-pruned seedlings grown in containers in direct contact with copper-impregnated ground cloth.

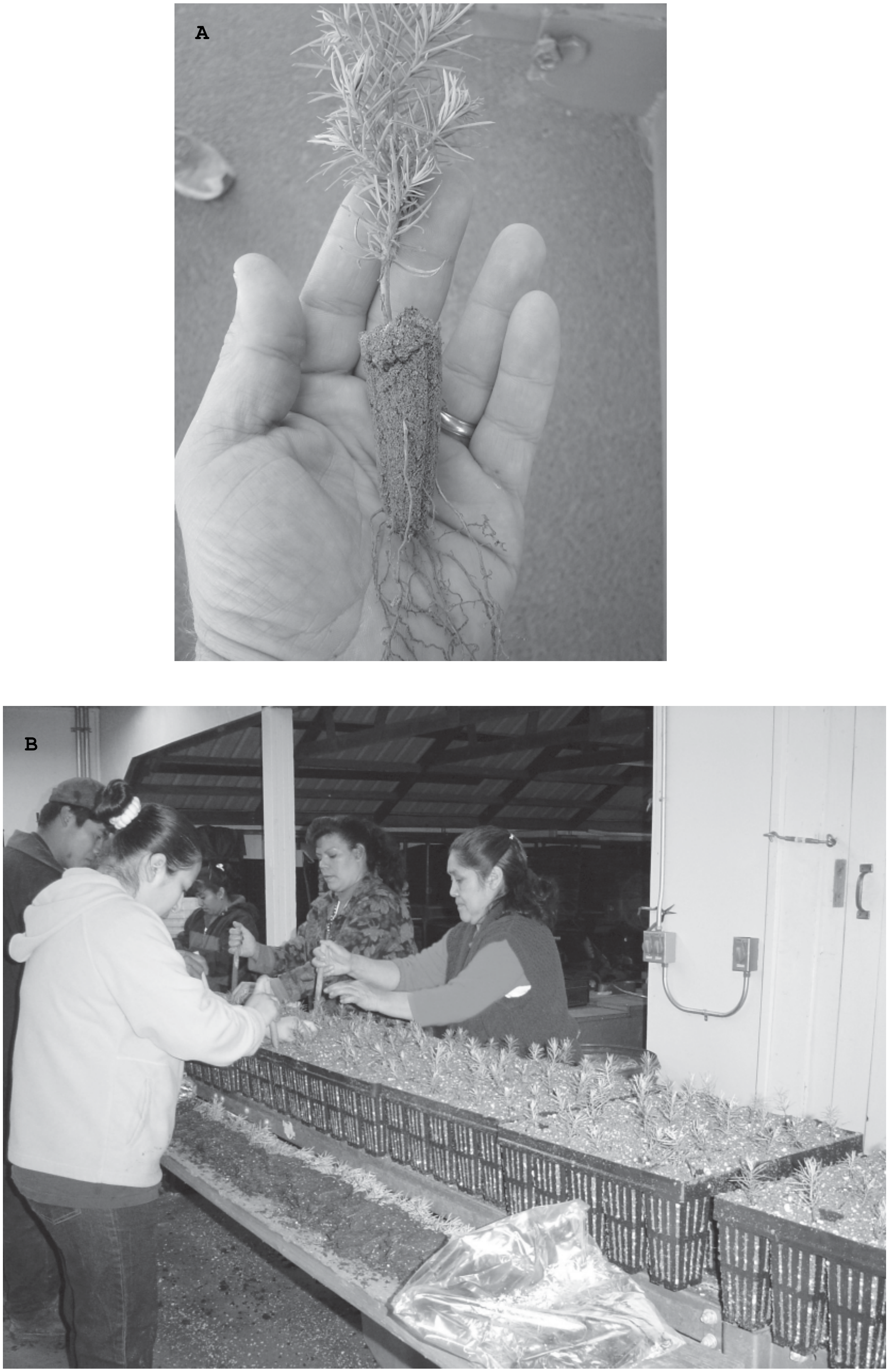


Figure 4—(Top) Seedling grown in small cavity for plug-in-plug system. (Bottom) Transplanting small plugs into larger cavities for the remainder of the growing season.

Individual Cell Systems

Individual cell systems allow for spacing of the crop as the top foliage (or canopy) becomes crowded (figure 5), although some growers use fixed cavity trays and space out their sowing. Seedlings can be shipped in the individual cells to protect against moisture loss and damage to the root system.

Clear Inserts

Clear inserts made to fit Styroblock™ containers can be used to monitor early root development by viewing the roots through the transparent insert. One disadvantage to this system, however, is the buildup of algae after 2 to 3 months in the upper two thirds of the tube. This buildup inhibits the ability to monitor root growth.

The cell inserts can be made in solid colors for creating an individual cell system within the Styroblock™ system (figure 6).

Larger Cavities or Pots

The demand for larger and larger cavities and pots is increasing (figure 7). The larger cavities have resulted in better survival and faster establishment following outplanting. In addition, plants can more easily outgrow brush competition.

White-Colored Pots or Cavities

Cells or pots at the perimeter of the growing areas can be subjected to extreme heat buildup during the growing season. This heat buildup can cause erratic germination and growth, damage to tender root systems and root collars, excessive dry down of the soil on the edge of the growing area, and even seedling mortality. Coloring pots or cavities white, especially on the outside edge of the growing compound, can reduce heat buildup in the cells (figure 8).

Container Handling and Culturing Systems

Cell or Cavity Sleeves

Native species tend to produce more fragile root systems than those found in conifer and hardwood species. Extraction of these plants from traditional containers can result in damage to tender root systems. Cavity sleeves are web mesh or thin plastic sleeves set into cavities or pots to make extraction and outplanting easier (figure 9). Sleeves are currently being developed for a variety of container systems, including the Ray Leach Cone-tainer™ supercell system.

Figure 5—Individual cell systems can be used to efficiently space a crop.

Figure 6—Inserts can be used to create an individual cell system in Styroblock™ containers.

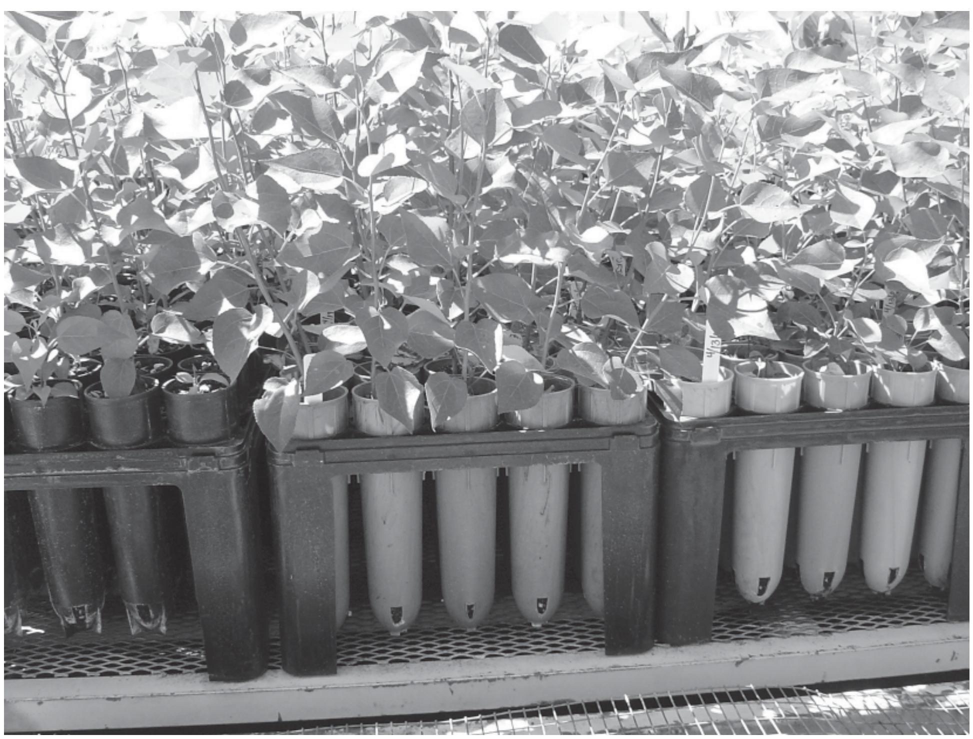


Figure 7—Large cavity pots (for example, 14-in (35.5-cm) deep D60 Deepots™) are becoming increasingly popular for seedling culture.

Figure 8—Coloring perimeter cavities white decreases heat build-up in cells during the growing season.

Figure 9—Cavity sleeves reduce the potential for damage to tender-rooted species during extraction from cells or pots.

Corralling Your Containers

Several sizes of Treepots™ are too tall and narrow to stand upright on their own. Growers are creating a variety of methods to support these containers. Fence wire mesh (4 in [10 cm] square mesh) stretched over a wooden frame allows removal of individual pots and spacing of pots (figure 10). Large horticultural pots (5 to 10 gal [19 to 38 l]) can support several large Treepots™ within them; milk crates will support 9 to 12 Tall One Treepots™. An inexpensive solution is to duct tape several pots together to create a stable unit that will stay upright.

Subirrigation

Subirrigation, or under bench watering, is an effective method to irrigate plant material with heavy top foliage. This type of plant material is difficult to water uniformly with the standard overhead watering systems. Sub-irrigation systems include bench-high flood systems or plastic-lined frames built on greenhouse floors. Flow trays (24.5 x 48.6 in x 5 in [62 cm x 123 cm x 13 cm]) have been developed for the Ray Leach Cone-tainer™ system (figure 11).

Trends In Container Sales

Sales records at Stuewe and Sons, Inc (Corvallis, OR) reveal that grower preferences for container type and size have varied over the past 5 years (figures 12a through 12d). Overall sales of small containers (≤5 in^3 [82 cm^3]) have increased with the popularity of the plug-in-plug growing system (figure 12a). Styroblock™ containers, in particular, have shown an increase in use for smaller cavities (figure 12b).

Use of the 5 to 10 in^3 (82 to 164 cm^3) cells has held steady or slightly decreased in most rigid container systems, presumably due to a decrease in traditional tree species culture and an increase in the number of native species growers (figure 12c). Use of individual cells of this size has remained fairly steady (figure 12d).

A surge in use of larger cavities and pots has become evident in the last 1 to 3 years, particularly in the individual cell systems. With the apparent increase in outplanting survival and establishment with larger plants, this trend is likely to continue.

Figure 10—Corralling pots with fence mesh is a popular method to keep potted stock upright.

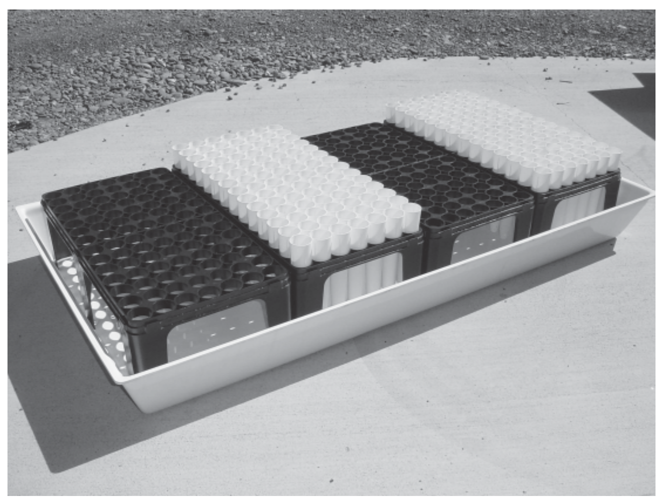


Figure 11—Flow trays have been designed for sub-irrigation with the Ray Leach Cone-tainer™ system.

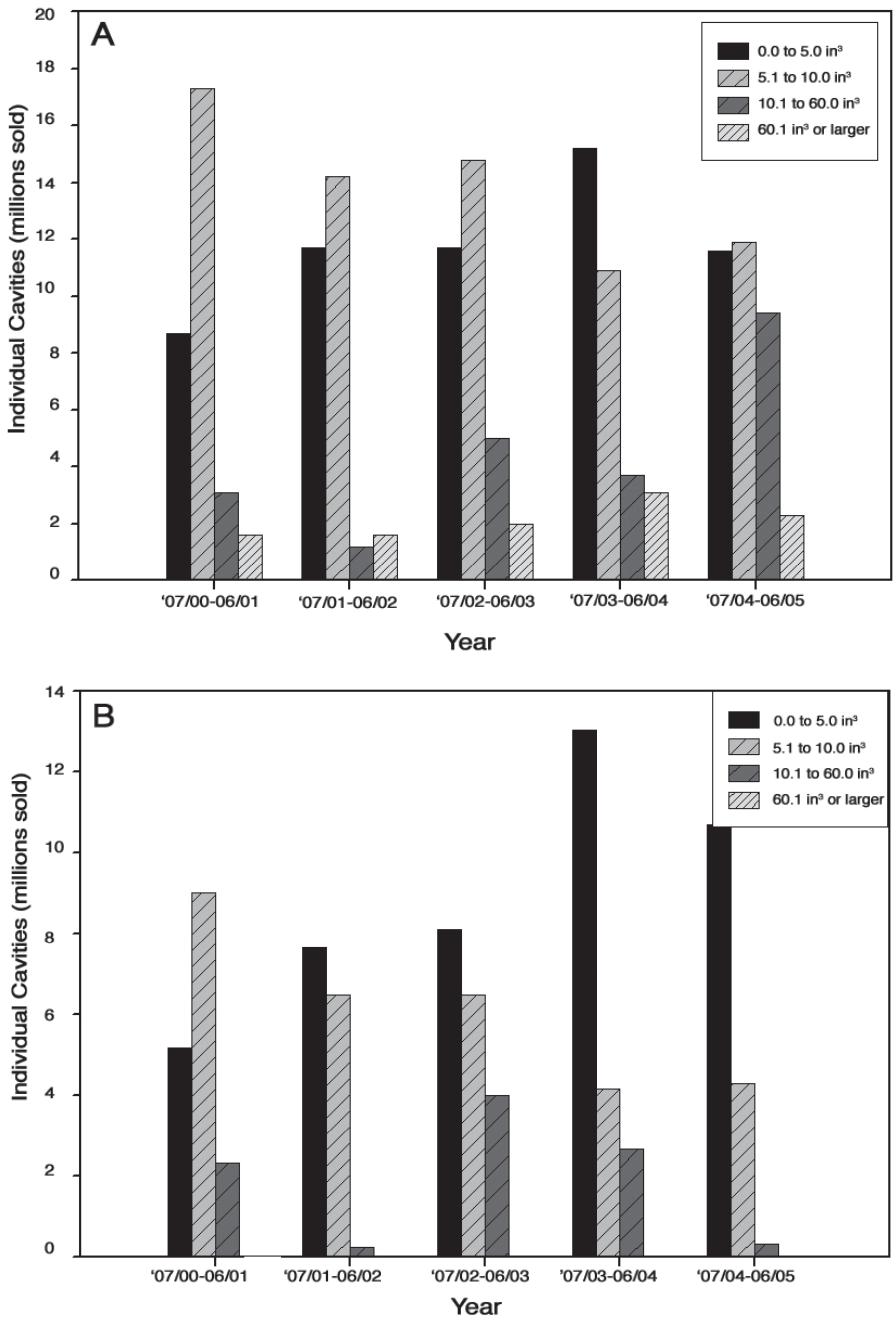
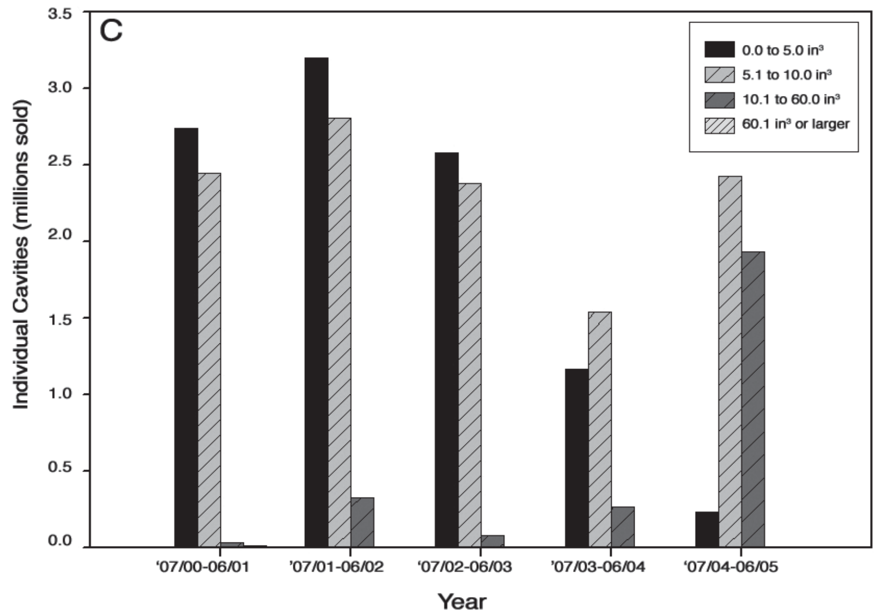


Figure 12—Variation in sales of cavity volumes in millions of individual cavities during the past 5 years: A) all types, B) Styroblock™ containers, C) rigid plastic trays, D) individual cell systems (continued on next pate).



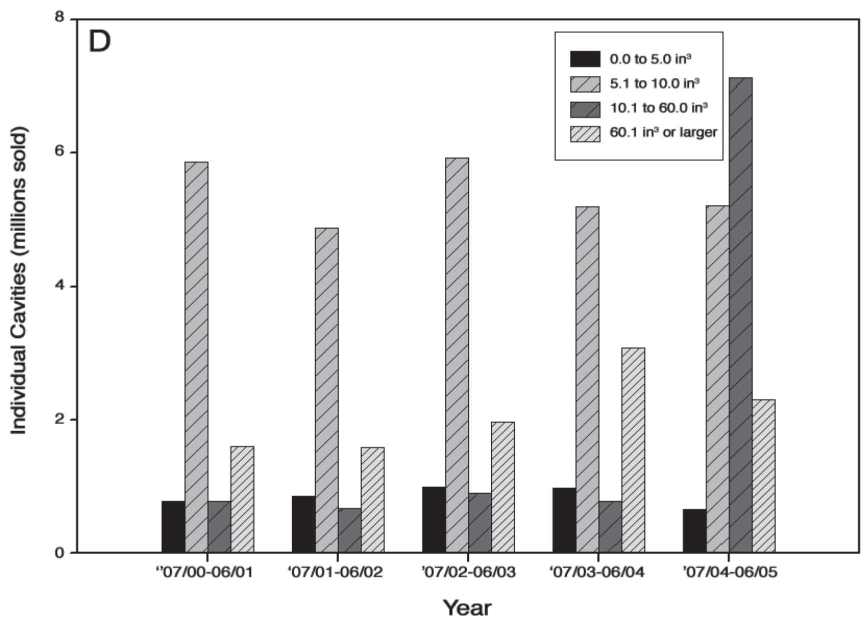


Figure 12—Continued.

Panel Discussion: Red Lake Forestry Greenhouse Operations

Gloria Whitefeather-Spears

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Keywords: greenhouse construction, container culture, red pine

Introduction

The Reservation

The tribal lands of the Red Lake Band of the Chippewa Indians are comprised of four districts in north central Minnesota. The Diminished Reservation, where most tribal members live and work, is approximately 532,000 ac (215,290 ha) in size and includes forests, wetlands, and grasslands. An additional 262,000 ac (106,030 ha) comprise ceded lands, called the Northwest Angle, that are geographically isolated by water and international boundaries from the State of Minnesota.

The Red Lake Reservation is unique for two reasons: 1) it is one of only two closed reservations, with large contiguous ownership by members of the band; and 2) there is a relatively low level of disturbance following the initial Euro-American settlement in the region.

History

In 1863, during the Sioux uprising, the U.S. government attempted to destroy all tribes in the State of Minnesota by removing their lands (cessions of land). The Dawes Act of 1887 and the Nelson Act of 1889 "legalized" these land cessions and took millions of acres of tribal lands. In 1889, the Red Lake Band sent a delegation to Washington, DC, to protest these acts. The Band stood alone and refused to consent to land removal. As a consequence, the Red Lake Indian Forest, a 50,000-ac (20,235-ha) tract, was created by a congressional act to give the Red Lake Band a permanent economic foundation. Although the lands, by law, belonged to the Red Lake Band, government mismanagement and timber company intervention continued.

A lawsuit was filed in 1951 on behalf of the Red Lake Band by Chairman Roger A. Jourdain claming mismanagement of timber. A total of 13 claims were filed against the U.S. government under the Indian Claims Commission Act. Claim number 6, for mismanagement of the Red Lake Indian Forest, was filed for losses in timber that exceeded U.S. $331.5 million. This claim was in process for 50 years.

Red Lake Forestry Greenhouse

History

Tribes with timberlands across the United States received funding allocated to tribal forest development programs in 1977. In 1978, Red Lake tribal members constructed the first greenhouse and became the only Midwest Region tribe to operate its own greenhouse. This greenhouse was a traditional Quonset style greenhouse covered with two layers of 6-mil polyethylene.

Present

The government provided tribes with additional funding in 1977, but no follow-up was done in this program. Although the lifespan of the greenhouse was 20 years, it is still standing and in use after 27 years, albeit in a state of disrepair.

Operations—The Red Lake Greenhouse grows a winter and a summer crop every year. Winter crops are grown in the greenhouse for up to 7 months, while summer crops are only grown for 3 months and are consequently much smaller. The highest outplanting success has been achieved when 2-year-old stock is used.

During the early years of greenhouse operations, seedlings were grown in the paper pot container system. However, it was found that after 5 to 8 years, the pots did not break down after outplanting. Due to this problem, Styroblock™ containers became the container system of choice in 1985. The 160/90 blocks (5.5 in^3 [90 cm^3]) were used, and this system continues to be used at present.

Outplanting—All tree planting is contracted out to tribal members; planters are required to show tribal membership and have a business license. Planters are given the opportunity to work in the greenhouse if interested. This allows them to see and understand the entire process, which in turn causes them to be more responsible during outplanting and more interested in survival rates. In addition, there is constant collaberation between the nursery and the planters, thus contributing to the production of quality seedlings necessary for reforestation success.

The Department of Forestry is considering requesting the involvement of loggers in outplanting operations. Loggers tend to pile slash in adjacent planted sites, causing damage to existing seedlings. If loggers were involved in outplanting, they would understand the work required and length of time necessary to reforest a site.

Future

The lawsuit filed in 1951 against the United States Government over mismanagement of tribal forest lands was finally settled in 2000 for a total of U.S. $53.5 million. The settlement required that a portion of that total (U.S. $40 million) be set aside in a permanent fund to be managed by the Red Lake tribe. It also required that a 50-year reforestation plan be developed by the tribe. The reforestation goals in this plan include the conversion of 1,000 ac (405 ha) back to pine, which will require the production of 1 million seedlings per year.

In 2000, a Greenhouse Task Force was formed, including tribal members and outside experts, to initiate a future plan for the greenhouses. This plan includes seven state-of-the-art greenhousese where each species could be grown in its own environment. Students from tribal schools will participate in greenhouse operations to learn the various aspects of nursery culturing. The entire Red Lake Department of Natural Resources (DNR) complex will include shadehouses and seed orchard areas. In addition, a fire center and helicopter pad and the main DNR complex, including Fisheries, land management, water management, environmental management, forestry, and wetlands will be located in this area.

Lessons Learned

Twenty-seven years of greenhouse operation and 5 years of greenhouse planning have resulted in these take-home lessons for anyone who wishes to construct a greenhouse of their own.

1. Setting a reasonable timeline early in the process for various segments of greenhouse construction is very important.
2. All contractor options must be explored. Because greenhouses are specialty projects, local contractors may not have the expertise to deal with this kind of construction. "Turn key" contractors are available, and it is best to hire personnel with experience.
3. Road blocks must be identified early, including all phases of planning, timing, and building.
4. All options should be kept open and alternatives should be formulated. Because projects must be started on time, alternative funding may be necessary, especially if politics are involved. Alternative construction sites may be necessary, and energy sources must be determined.

Acknowledgments

The greenhouse experts consulted in 2000 included Thomas D. Landis, USDA Forest Service, retired; Richard W. Tinus, USDA Forest Service, deceased; R. Kasten Dumroese, USDA Forest Service; John W. Bartok, Jr., University of Connecticut, Emeritus.

Whitebark Pine Guidelines for Planting Prescriptions

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Abstract: This paper reviews general literature, research studies, field observations, and standard Forest Service survival surveys of high-elevation whitebark pine plantations and presents a set of guidelines for outplanting prescriptions. When planting whitebark pine, the recommendations are: 1) reduce overstory competition; 2) reduce understory vegetation, especially grasses and sedges; 3) avoid outplanting in swales or frost pocket areas; 4) provide shade protection; 5) plant where there is protection from heavy snow loading; and 6) provide adequate growing space.

Keywords: whitebark pine, *Pinus albicaulis*, reforestation, tree planting, pocket gophers, white pine blister rust, mountain pine beetle, cones, seeds, fire suppression

Introduction

Whitebark pine (*Pinus albicaulis*) is a keystone species in high elevation ecosystems across its range. It has a wide geographic distribution that includes the high mountains of western North America including the British Columbia coastal ranges, Cascade and Sierra Nevada ranges, and the Northern Rocky Mountains from Idaho and Montana to the edge of the Wyoming basin (figure 1). It is a hardy subalpine conifer occurring in elevations ranging from 5,000 to 11,000 ft (1,525 to 3,350 m), growing and surviving along ridge tops and other tough sites where no other tree species regenerate. Unfortunately, many of these fragile alpine ecosystems are losing whitebark pine as a functional community component. Throughout its range, whitebark pine has dramatically declined over the past 50 years due to the combined effects of insects, introduced diseases, and successional replacement.

Why Do We Care?

The integrity of the whitebark pine ecosystem affects watershed conditions including snow accumulation, snow melt, and quantity and timing of water flow; it contributes to rapid cover restoration after fire, blowdown, or avalanches; it is a major component of ecosystem diversity in the subalpine zone; it is a significant food source for the threatened grizzly bear, and is foraged on by black bear, birds, and other animals. Clark's nutcracker populations depend on whitebark pine as a food source and are the main seed disseminators. Whitebark pine enhances aesthetic views as recreationists admire the often distorted and windblown shaped krumholtz form of whitebark pine.

Without prompt action, we will lose this important component in cases where natural selection of blister rust resistant trees does not act fast enough. Outplanting whitebark pine is one management strategy that works with natural processes to keep or restore the presence of whitebark pine where seed supplies of whitebark pine are inadequate.

Decline of Whitebark Pine

White pine blister rust (*Cronartium ribicola*) has caused rapid mortality of whitebark pine over the last 30 to 50 years. Keane reported in 1993 that 42 percent of whitebark pine in western Montana have died in the previous 20 years, with 89 percent of the remaining trees being infected with white pine blister rust (Keane and Arno 1993). This has only multiplied in affects

Figure 1—Natural distribution range of whitebark pine in western North America. Diagram courtesy of Whitebark Pine Ecosystem Foundation Web site, reproduced from Arno and Hoff (1989).

since his study. In drier-colder conditions such as east of the Continental Divide, the rate of spread of blister rust has been slower and mortality is low. However, infection rates are increasing. Additionally, white pine blister rust kills the upper portion of the cone bearing trees before the tree succumbs to the disease, effectively ending seed production and the opportunity for regeneration.

Currently, Montana is experiencing an active mountain pine beetle (*Dendroctonus ponderosae*) epidemic. The impact to whitebark pine is the worst seen since the 1930s (Gibson 2005). Mountain pine beetle tends to preferentially attack large older trees, which are the major cone producers, again reducing the potential for seed production and subsequent regeneration. Unfortunately, in some areas, the few remaining whitebark that show blister rust resistance are being attacked by beetles, thus accelerating the loss of key mature cone-bearing trees.

Fire suppression over the past few decades has enabled other species, such as subalpine fir (*Abies lasiocarpa*) and Engelmann spruce (*Picea engelmannii*), to encroach into some high-elevation stands that were historically dominated by whitebark pine. This change in cover type and increased fuel loading, including ladder fuels, is creating higher fire-regime-condition-class situations typically not found in whitebark pine stands. Barrett (2004) found that whitebark pine stands typically fall in the Mixed Severity 3 Fire Regime with a 50- to 275-year mean fire interval, indicating highly variable fire patterns. These conditions of intense competition are also not conducive to producing good cone crops and successful natural regeneration. This is evidenced by the lack of young age classes in many areas of the Northern Rockies (Kendall and Keane 2001).

Ecological Environment

The practice of growing and outplanting whitebark pine is relatively new compared to traditional conifers, but it is gaining in importance, although at small scales. There is limited research on planting whitebark pine, but knowledge about the physiological and ecological characteristics of the species is increasing. With this knowledge, and the experiences from a few reforestation specialists from Montana and Idaho forests, we have outlined some guidelines for planting prescriptions. Particularly, we have considered the natural conditions of where whitebark pine grows, what conditions allow for good cone producing trees, where it naturally regenerates, and under what conditions seedlings establish.

The ecological niche for whitebark pine differs from other, more traditional, managed tree species where outplanting is common. It is adapted to a wide range of sites. On milder sites, however, it is out-competed by other species. It tends to have the competitive advantage on windswept ridgetops, shallow soils, and high elevation sites. It is typically a pioneer species. In the more mesic portions of it range, it is successional to shade tolerant species such as spruce or subalpine fir. In the drier portions, it maintains itself in a self perpetuating climax species. In the Northern Rockies, it is present on a variety of habitat types defined by Pfister and others (1977), although it is most common as a long-lived seral species on the *Abies lasiocarpa-Pinus albicaulis*/*Vaccinium scoparium* and *Abies lasiocarpa*/*Luzula hitchcockii* types (Arno and Hoff 1989).

Whitebark pine appears to be relatively shade intolerant, with tolerance similar to western white pine (*Pinus monticola*) and interior Douglas-fir (*Pseudotsuga menziesii* var. *glauca*), and less shade tolerant than subalpine fir, spruce, and mountain hemlock (*Tsuga mertensiana*). It is more tolerant than lodgepole pine (*Pinus contorta*) and alpine larch (*Larix lyallii*) (Arno and Hoff 1989). Whitebark pine is most abundant on warm aspects and ridge tops having direct exposure to sun and wind. It is less abundant on sheltered north-facing slopes and in cirque basins where other more shade tolerant species dominate. Nevertheless, the tallest and best formed whitebark pines are often found in high basins or on gentle north-facing slopes. Although it is drought resistant, it is not frost resistant, at least during the growing season and for young establishing seedlings.

One of the earlier plantation trials for whitebark pine began in 1987 on Palmer Mountain on the Gallatin National Forest near Gardiner, Montana. One portion of the study evaluated outplanting survival based on physiographic location across the study site (figure 2). Trees were planted in rows starting in a swale, then up a 15 percent slope, over a

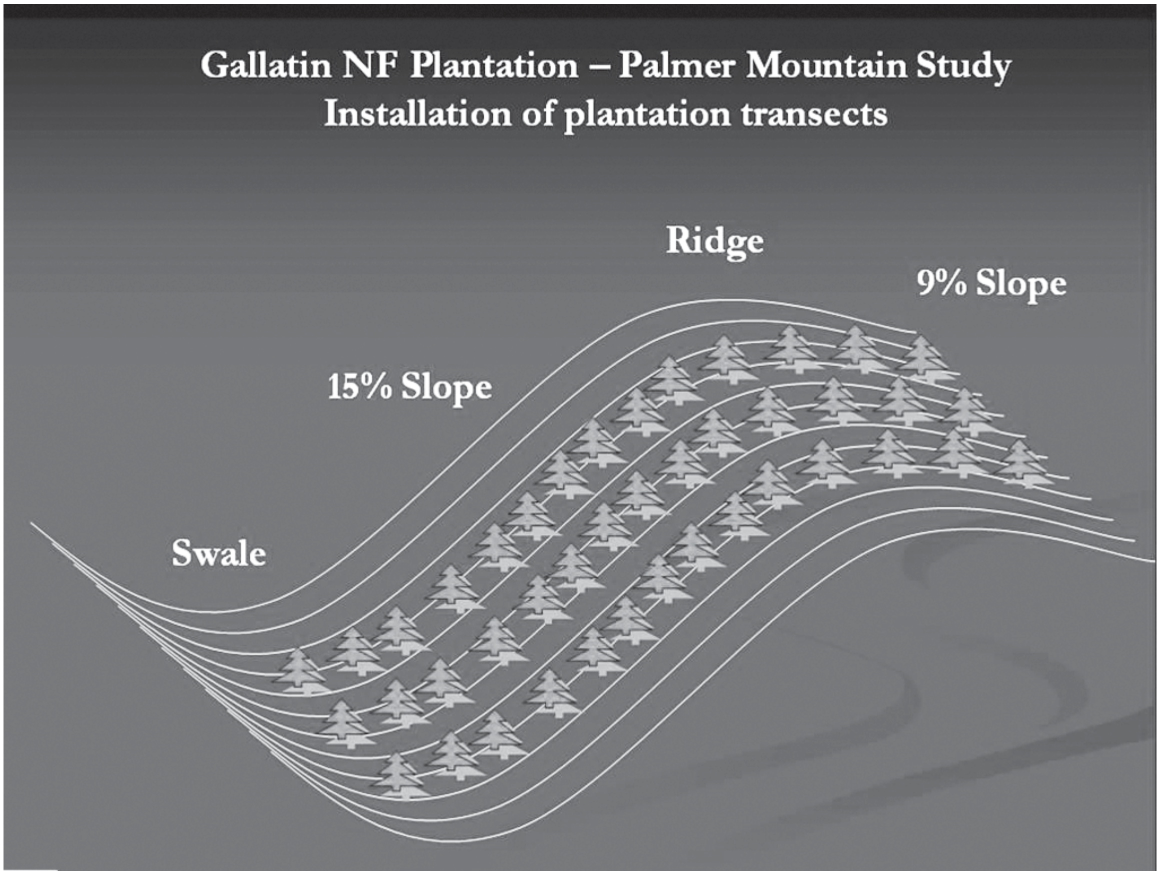

Figure 2—Schematic of whitebark pine seedlings planted across four physiographic locations on Palmer Mountain on the Gallatin National Forest near Gardiner, Montana.

ridge, and across a bench of less than 9 percent slope. While long-term results are not yet available, early results indicate the highest survival on drier ridges and gentle benches (McCaughey 2005) (table 1). Total survival decreased over the 11-year period, with the largest drop occurring in the first 5 years after outplanting. Eleven years following planting, survival was highest (47 and 39 percent) on the ridges and benches and lowest on the swales and steep slopes adjacent to the swale. Survival differences are probably due to the combined effects of other conditions based on topographic position. Gopher activity was visually higher in the swales and adjacent slopes where soils were deeper and grasses and forbs more abundant (McCaughey 1994a).

Table 1—Percentage survival of 11-year-old whitebark pine seedlings planted on four physiographic locations (swale, 15 percent slope, ridge, and 9 percent bench) on Palmer Mountain on the Gallatin National Forest in Montana.

	Physiographic location			
Year	Swale	15% Slope	Ridge	9% Bench
1987	100	100	100	100
1988	80	96	100	95
1989	58	86	100	86
1992	2	21	57	52
1993	2	20	47	44
1998	2	20	47	39

A second whitebark pine plantation study near Cooke City, Montana showed that from 1992 to 2001, survival on moist sites dropped from 100 to 50 percent. On dry sites, however, survival only dropped to 86 percent. Again, drier more severe sites with less vegetative competition and animal disturbance were better suited for whitebark pine survival. Long-term results of this study, along with results of a variety of other studies, tree row survival surveys, and field observations relating to site conditions, outplanting seasons, and tree spacing, will further aid silviculturists in refining prescriptions. Results and long-term survival are just beginning to become available for some research studies.

A regeneration study in western Montana showed that whitebark pine seedlings survive better when grown in association with grouse whortleberry *(Vaccinium scoparium)*. While vegetation competition is not favorable for whitebark pine survival, Perkins (2004) found that seedlings survived best when outplanted with grouse whortleberry or in bare ground. Poorest survival was in association with sedges typically found on moister sites. Seedlings planted in bare ground with no site amelioration survived at intermediate levels. Her study identified a positive correlation to growth when grouse whortleberry was present, better than even bare ground. While there may be positive effects caused by whortleberry reducing soil moisture evaporation and shade protection, its greater benefits may be by assisting seedlings via a mycorrhizal relationship or other below ground interactions. Further studies are necessary, but it appears that it is not by accident that whitebark pine and grouse whortleberry are commonly found together.

Additional Observations

Although whitebark pine survives and can thrive at lower elevations and on more productive sites, it has lower survival due to greater impacts from competition and high gopher problems. It also does not tend to dominate and create wide crowned individuals due to competition and crowding from faster growing species. Cone crops on small crowned trees grown in dense stands are smaller than crops from open-grown trees (figure 3). The real niche for whitebark pine tends to be on shallow well-drained soils, steeper slopes, and windy exposures.

Whitebark pine appears to have stable horizontal resistance to blister rust, allowing management strategies to incorporate the resistance genes into outplanting programs (Hoff and others 2001). Keane and Arno (2001) describe a seven-step process that is important in whitebark pine restoration efforts, and managers need to add planting to this process as a critical reforestation tool. Management options include even- or uneven-aged silvicultural systems that provide light and localized site prep (Arno and Hoff 1989).

The best chance for success in restoring and maintaining whitebark pine is to outplant seedlings with blister rust resistance from a natural selection processes. Whitebark pine may have the highest susceptibility to blister rust of any of the 5-needle pines in North America; however, individual trees express notable resistance to blister rust (Hoff and others 1994). Cones should be collected from trees expressing resistance as a first but critical step towards improving rust resistance.

Growing the Whitebark Pine Seedling

Whitebark pine has been described by Farmer (1997) as one of the pines with a hard but permeable seed coat. Collecting viable whitebark pine seeds needed for production of nursery stock has been difficult because of seed consumers such as squirrels and the Clark's nutcracker. Cone production is very sporadic, with good cone crops occurring only every 3 to 5 years. Older open-grown trees with wide crowns produce the most cones and can be easily climbed when collecting cones (figure 3).

Seeds need adequate time in a conditioning environment to mature to the point that they will have adequate germination potential. Collect too soon and the seeds are not ripe; collect too late and rodents and birds will deplete the seed crop. McCaughey (1994b) recommends periodic collection of cones to determine maturity and then make final collections when embryo to total seed length ratios are above 0.65 and after endosperm to total seed length ratios reach 0.75 percent or above. Delay collecting if these conditions are not met, squirrel caching is minimal, and nutcrackers have not begun to collect seeds from the stand. If harvesting of cones and seeds by animals has begun but cones are not ripe, cone collection can begin but the manager must be aware that germination potential will not be optimal.

Nutcracker planted seeds are stratified by overwintering in cold environments where they are subjected to long periods of cold, moist conditions. These conditions help the seeds to overcome physical and physiological barriers to

Figure 3—Mature large crowned whitebark pine produce the most cones.

germination. Dry spring conditions reduce potential for seeds to imbibe water, resulting in seeds lying dormant for that year. Whitebark pine seeds can delay germination for up to 3 years after planting, germinating when spring moisture is adequate (McCaughey 1993). In certain wet years, germination can continue throughout the summer and into the fall (McCaughey and Tomback 2001)

Taking these lessons into the greenhouse, nursery experience shows that there is a variety of techniques to break various dormancy mechanisms. The simplest method is cold stratification for very long periods of time—over 4 months. Research shows that 45 to 60 days is the minimum needed. However, this procedure may not yield the highest germination rates (McCaughey and Tomback 2001). To increase germination reliability, the USDA Forest Service Coeur d'Alene Nursery has developed a multiple-step protocol for whitebark pine (Burr and others 2001). They use a warm and cold stratification, and then manually nick the seed coat of seeds that do not germinate on their own. They report that 90 percent of the seeds that will germinate do so in the first 2 weeks with this method. Seeds are geminated in a germinator and "germlings" are planted into containers. A recent development is an automatic seed scarifier (Gasvoda and others 2002), which mechanically nicks the seed without damaging the embryo. This promises to reduce labor costs and time in nursery operations.

As in the field, nursery-grown seedlings are slow-growing, which is typical of other high elevation species. Two growing season are required to produce plantable seedlings. Germination occurs throughout the first growing season. Secondary needles may develop the first season but they are most prevalent during the second growing season. Aggressive root development generally occurs. Recently emerged seedlings are vulnerable to a variety of damaging agents, including heat damage. Even with increased stem diameter, seedlings are easily damaged, and thus must be shaded during the warmest part of the growing season (McCaughey and Tomback 2001). Nursery growers observe that whitebark pine seedlings go into dormancy quite easily and early. Therefore, maintaining a long photoperiod will encourage a longer growing season.

Target seedlings are ready for outplanting in early July in Montana with bud set complete and root and caliper growth set to continue in the field. The soil moisture of the outplanting sites is generally good at this time due to late snow melt. Districts should plan for very short tree storage from the time of extraction to planting. If soil moisture is expected to be good in the fall, the nursery can continue the growing regime and extract seedlings just before fall outplanting. Root growth may occur but most will occur in spring. Our growers are using a large container, a Ray Leach Conetainer™ supercell (10 in^3 [164 cc]), to achieve the best seedlings.

Guidelines For Planting Prescriptions

Based on ecological and physiological information, planting trials, and experience in the Northern Rocky Mountains, we recommend the following guidelines be included in outplanting prescriptions:

1) Reduce overstory competition to increase light and day length to improve the effective growing season.

2) Reduce most understory vegetation, especially grasses and sedges, to reduce competition for available soil moisture. However, do not aggressively remove grouse whortleberry during site preparation. If grouse whortleberry is not present, then creating a planting site of bare ground is the best alternative.

3) Avoid outplanting in swales or frost pockets; consider the topographic position as well as the actual planting spot. Young whitebark pine seedlings do not appear to be frost hardy during the growing season. Ridge tops or exposed slopes are suitable.

4) Provide shade and protection for newly outplanted trees to improve water utilization and to reduce light intensity and stem heating. Planting by stumps or other stationary shade is important.

5) Plant where there is some protection from heavy snow loads and drifting snow. Stumps, rocks, and large logs are favorable microsites (figure 4).

6) Do not overcrowd outplanted trees to avoid long-term inter-tree competition. Open grown trees have the largest crowns and produce the most cones. Tree form is not as important because the purpose is to establish trees for long-term regeneration, cone production purposes, aesthetics, and a variety of other reasons that do not include timber production. Adjust spacing guides based on expected survival. At 50 percent survival, planting density should be 6.1 m by 6.1 m (20 ft by 20 ft), producing 247 live seedlings/ha (100/ac).

7) Plant when there is adequate soil moisture. Summer and fall outplanting have been successful, thereby avoiding the need for long expensive snow plows and delayed entry due to heavy spring snow loads.

8) Plant large, hardy seedlings with good root development (figure 5).

Conclusion

Planting whitebark pine is only a small part of the whitebark pine restoration strategy. Enhancing conditions for natural regeneration with prescribed fire or managed wildland fire are major actions that will make significant contributions to restoration. With proper attention to planting prescriptions and ensuring appropriate nursery culturing regimes, we can augment blister rust resistance and survival of outplanted trees where natural seed sources and natural regeneration are limited.

Genetics programs, which are testing for genetically improved seeds patterned after white pine and sugar pine blister rust resistance programs, will be a great aid in restoration. However, where opportunity exists to plant whitebark pine, we cannot afford to wait on the development of rust resistant tree stock.

Throughout much of its range, silviculturists are initiating the outplanting of whitebark pine as one small tool in their bag of management options. Planting prescriptions for whitebark pine are similar to those for other species on

Figure 4—Whitebark pine seedling outplanted in the shade of a stump to protect it from intense heat, help with conservation of water, and to act as a barrier to shifting snow and soil.

harsh sites, but whitebark pine fills a niche that we would typically avoid planting with other conifers. With continued monitoring in the field and with research studies, we can refine the prescriptions for survival, increase populations of rust resistant trees, and contribute to the population of regenerating whitebark pine. Working with our nursery partners in developing an efficient and affordable growing regimen that develops target seedlings is the key to outplanting success for whitebark pine.

Figure 5—Whitebark pine seedling grown in a large container plug showing a well developed root system that helps seedlings adapt to planting sites. Photo courtesy of the Targhee National Forest photo library.

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Whitebark Pine Germination, Rust Resistance, and Cold Hardiness Among Seed Sources in the Inland Northwest: Planting Strategies for Restoration

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Abstract: A synthesis of several studies highlights above-average performing seed sources (n = 108) of whitebark pine (*Pinus albicaulis*), which practitioners can utilize for restoration, wildlife habitat improvement, and operational planting programs. It is the first report of this magnitude of blister rust resistance for this species. Whitebark pine does have genetic variation and demonstrated resistance to white pine blister rust, increasing from the southeast to the northwest in the Inland Northwest. Early outplanting reports have shown that some seedlings have frost damage or exhibit increased mortality in cold pockets or swales. Cold hardiness, measured in late winter on a smaller sample of sources (n = 55), also showed genetic variability increasing from the northwest to the southeast. Seed zones were delineated by Mahalovich and Hoff (2000) based on information on relative rust hazard and demarcation of mountain ranges. These geographic seed zones support conservative seed transfer with a special emphasis on blister rust infection levels. Sufficient variability exists to maintain these seed zone boundaries, because whitebark pine exhibits more of an intermediate adaptive strategy as compared to the generalist adaptive strategy of western white pine (*P. monticola*). Based on this composite information, it is feasible to outplant whitebark pine without the additional delay of waiting until blister rust resistant seedlings are developed from a breeding program. There are sources within each seed zone that have both rust resistance and greater cold hardiness, so those factors should not limit tree planting for restoration or critical wildlife habitat improvement objectives.

Typical stock orders involve container-grown seedlings. A comparison between Economy and copper-lined Ray Leach Super Cell Cone-tainers™ (10 in^3 [164 cm^3]) shows no advantage to using copper lining.

Keywords: *Pinus albicaulis*, progeny test, genecology, heritability, electrolyte leakage test, index of injury

Introduction

Whitebark pine (*Pinus albicaulis*) plays a vital role as a keystone species in upper subalpine ecosystems, likely determining the ability of large numbers of other species to persist in the community (Primack 1998). Whitebark pine is a food source for grizzly bears, Clark's nutcrackers, and red squirrels, and is a foundation species for watershed protection by regulating runoff and reducing soil erosion. It is a species that quickly becomes established as a pioneer species following disturbance. Seedlings are very hardy and tolerate drought more readily than other conifers.

The number of acres in whitebark pine is rapidly dwindling (Scott and McCaughey 2006). High infection levels of white pine blister rust (*Cronartium ribicola*) are causing extensive mortality, with a secondary impact of losses in cone production whenever reproductively mature trees are infected and killed. Epidemic infections of mountain pine beetle (*Dendroctonus ponderosae*), selection against a pioneer species by fire suppression, and catastrophic wildfire are also causing extensive mortality. Whitebark pine is susceptible to cone (*Conophothorus* spp., *Dioryctria* spp., *Eucosma* spp.) and seed insects (*Megastigmus* spp.), seed-borne fungal diseases (*Sirococcus strobilinus*, *Calocypha fulgens*), and damping-off in seeds and germinants (*Fusarium* spp.). Once sufficient cone production is absent or curtailed, the primary dispersing agent, Clark's nutcracker (*Nucifraga columbiana*), moves onto other species like ponderosa pine (*P. ponderosa*) or other locations with the possibility of not re-colonizing the impacted area at a later time. Successful natural regeneration is not keeping pace with mortality. Ironically, the reasons for dwindling acres of whitebark pine identified above are also the same factors that make natural regeneration a questionable tool for restoration.

Rationale commonly cited for not proceeding with outplanting include: whitebark pine is not a commercial tree species; blister rust resistant seedlings are not available (this paper will show they now are); and costs of producing a seedling are perceived to be too high. Container seedling costs in northern Idaho range from U.S. $0.75 to 3.00 per seedling depending on nursery, container type, and seedling age (Burr 2005; Klinke 2005).

Whitebark pine may have one of the highest susceptibilities to blister rust of any of the five-needle pines (Bingham 1972; Hoff and others 1980), but individuals express notable resistance. An effective restoration program involves identifying and developing blister rust resistance. To accomplish that objective, patterns of genetic variation in a group of key adaptive traits need to be known, as well as their relationships to each other (genetic correlations) and how heritable they are. The strength and repeatability of each trait determines the restoration strategy for each species. Rust resistance in whitebark pine is a two-pronged strategy patterned after western white pine (Mahalovich and Dickerson 2004; Mahalovich 2005). First, families exhibiting resistance following an artificial inoculation with blister rust are selected based on an index score. Then individuals within superior families are selected for additional rust resistance, cold hardiness, and height performance. This is the first reported rust screening of this magnitude in whitebark pine.

The key to all of these traits is a focus on rust resistance (the ability to survive repeated infections), rather than the complete absence of infection (immunity), which would apply undue selection pressure on the rust, placing the host species at a continued disadvantage over time. Only one trait out of the seven evaluated typifies an immunity response (no-spot) (table 1).

Whitebark pine is hardy and drought tolerant; however, germinants and seedlings are stressed in frost pockets and cold swales (Scott and McCaughey 2006). In general, climatic races become adapted to particular environments as a result of natural selection. Typically, sources from milder climates often are not sufficiently cold-hardy when moved northward or when lower elevation sources are moved up in elevation. The practical implication of cold hardiness is also critical in restoration efforts in addition to rust resistance. Physiological testing is a means to determine the condition of nursery stock and to predict how it will respond to treatment or end use. The electrolyte leakage test can be used to measure cold hardiness and detect tissue damage. The principle of this test is that when cell membranes are damaged, electrolytes leak out into the water in which the tissue is immersed and can be measured by the conductivity of the solution. The test for damage is nonspecific; but in the case of cold hardiness, the damaging agent is known because the tissue is frozen. The 50 percent index of injury is used as the benchmark for cold hardiness because it is usually the midpoint on the regression curve of temperature versus injury and has the smallest confidence interval (Tinus 2002).

Materials and Methods

Stratification, Sowing, and Growing of Test Seedlings

Seeds for the test were sown in 1999 at USDA Forest Service Coeur d'Alene Nursery, Coeur d'Alene, Idaho from cone collections representing the geographical range of the species in the northern Rocky Mountains. Selected seedlots span 5° in latitude, 9° in longitude, and 1,900 to 3,300 m (6,235 to 10,825 ft) in elevation. Whitebark pine is a wind-pollinated species. These open-pollinated, individual-tree cone collections are assumed to be genetically representative of the area in which they were collected and are hereafter referred to as seed sources. The target number of sources for the study was a minimum of 100; 115 had an adequate number of seeds to proceed with sowing. During this timeframe, a large operational cone collection was made on the Shoshone National Forest (Wyoming). Requests to sow and plant from this seedlot throughout the northern Rockies were being made without information on whether the collection was rust resistant. As a result, sufficient numbers of container seedlings were reserved from general nursery operations to be included in the rust inoculation and testing phase of this study. Examination of the origin data for all seedlots suggests 54 unique areas are represented overall.

For seed coat disease control prior to stratification, seeds were soaked in a bleach solution of one part 6 percent sodium hypochlorite to two parts water for 10 minutes. Seeds were then rinsed four times in fresh water, placed in mesh bags, and soaked in cold running tap water for 48 hours. After a 28-day warm stratification period at 20 °C (68 °F) and a 1-hour running water soak, the mesh bags of seeds were placed in new 1-ml plastic bags and placed in a dark stratification room at 2 °C (36 °F) for 60 days. The weekly running water soaks were continued during this cold stratification as described by Burr and others (2001).

At the completion of cold stratification, seeds were not nicked with a scalpel to overcome seed coat dormancy, but instead were sown directly into the sphagnum peat-Douglas-fir wood chip blended growing medium in January 1999 in Ray Leach Super Cell Cone-tainers™ (Super Cells) (10 in^3 [164 cm^3]). A smaller sample of these Super Cells had copper lining to evaluate differences between the Economy and copper-lined containers. The growing environment was monitored and controlled with a computer integrated system. Heat was applied as needed with gas forced-air heaters, with heat tubes situated under benches. Photoperiod extension was accomplished with sodium vapor and metal halide lamps.

Table 1—Description of blister rust resistance traits, mechanisms, and selection strategies used in whitebark pine in the USDA Forest Service Northern Region.

Trait Name	Description	Selection strategy	Traits used to determine index score	Mean[a]	Standard deviation
Needle lesion frequency (NLF)	Reduced number of needle spots	Family Selection	X	0.36	0.58
Early stem symptoms (ESS)	Reduced number of early stem symptoms (cankers)	Family Selection	X	0.07	0.10
Bark Reactions (BR)	Increased number of callus formation, walling-off cankers, and thereby preventing further infection	Family Selection	X	0.11	0.14
Canker alive or tolerance (CANKALIV)	Increased survival even with active cankers	Family Selection	X	0.57	0.26
Bark Reactions (BR)	Increased number of callus formation, walling-off cankers, and thereby preventing further infection	Individual-Tree Selection		0.06	0.24
No spots (NO)[b]	No spot symptoms, no cankers	Individual-Tree Selection		0.15	0.36
Needle shed (NS)	Shedding of infected (spotted) needles in the first fall following inoculation	Individual-Tree Selection		0.07	0.25
Short Shoot (SS)	Isolation of infected needle fascicles; mycelium do not enter branches	Individual-Tree Selection		0.20	0.40

[a] The proportion of the number of individual trees exhibiting the trait divided by the total; values for the family selection traits are based on plot means.
[b] The no-spot trait is the only one to infer immunity—no spotting or canker development are evidenced on a tree; in all other traits, the tree becomes infected but is able to ward off or survive blister rust.

Temperature, photoperiod, water (pH adjusted to 5.5 using phosphoric acid; applied when needed as determined by tray weights), and nutrient availability (Peters Professional® Conifer Grower™ (20N:7P_2O_5:19K_2O), Peters Professional® Conifer Finisher™ (4N:25P_2O_5:35K_2O), magnesium sulfate, calcium nitrate (15.5N:0P_2O_5:0K_2O:19Ca), phosphoric acid, and iron (Fe) were controlled at the time of germination, and during early growth, exponential growth, and the hardening phase. Cleary 3336™ (thiophanate-methyl) fungicide was applied through the irrigation boom to control damping off symptoms caused by *Fusarium* spp.

First and Third Year Greenhouse Data Collection

Survival (presence/absence) and percentage germination were obtained in July 1999 for each seed source. The early season growing regime for the third year of growth was the same as the first 2 years. In preparation for the selection and randomization of seedlings to be inoculated in the fall, all trays of seedlings were moved during the last week of May 2001 from the Quonset-style greenhouse to a fiberglass panel covered greenhouse with a motorized roof vent for venting excess heat during the last week of May 2001. Survival (presence/absence), *Fusarium* spp. infection (presence/absence), terminal damage (presence/absence), and height (mm) were obtained in July 2001 prior to inoculation.

Artificial Inoculation of Treatment Seedlings With Blister Rust

Due to the slower growth of whitebark pine relative to western white pine seedlings, 3-year old rather than 2-year old seedlings were artificially inoculated to have enough surface area of secondary needles for infection (Mahalovich and Dickerson 2004). The target number of seedlings per source was 144 in an effort to pick up some of the resistance traits that are in low frequency, similar to western white pine (Mahalovich 2005). To adequately assess the traits that are thought to be under polygenic inheritance, a minimum of four replications (36 seedlings randomly assigned per replication) are needed to provide reliable estimates. A separate randomization of seedlings, among four replications, was made for the control lots (uninoculated material).

The inoculum source comes primarily from an established *Ribes* spp. garden at Lone Mountain Tree Improvement Area (Idaho). Shrubs included in the garden for whitebark pine inoculations are made up of *Ribes* spp. found in whitebark pine cover types: *R. cereum*, *R. lacustre*, *R. viscosissimum*, and *R. montigenum*. *Ribes* spp. bushes were inoculated in mid to late June with aeciospores collected from active blister rust cankers on whitebark pine across northern Idaho and Montana. Branches from infected plants were used to spread the uredia spores to intensify the infection on the *Ribes* spp. bushes during late July and early August. The garden was irrigated frequently during this period to maintain high relative humidity under the shade cloth structure, which also helps to spread uredia.

Inoculum is collected from the *Ribes* spp. garden when telia horns have ample basidiospore production. The timing of the collection is determined by "plating" sampled leaves in agar petri dishes. Leaves are kept in the petri dishes overnight to allow time for spore drop. The dishes are inspected under a 10X dissection microscope. A decision is made to collect leaves from the garden when the average spore drop count has reached 5 to 10 spores per dish.

Approximately 2,500 *Ribes* spp. leaves were collected for the inoculation screening. The garden was equally divided into 12 sections prior to collection, with the number of leaves per species section determined by the rate of infection and inoculum production present. The goal was to collect at least 200 leaves per section. Leaves were collected no sooner than 24 hours prior to inoculation. Harvested leaves were packaged in groups of 50 in plastic sandwich bags, and a small amount of water was added to the bottom of each bag to keep the leaves moist and to prevent the telia from drying out. Leaves were stored in camp coolers for transportation from the collection point and were refrigerated until used.

An inoculation chamber was created by tightly enclosing a double, hooped framehouse with plastic and canvas to maintain optimum humidity and temperature and to minimize air movement. Soaker hoses placed on the floor were used to maintain humidity in the inoculation structure as close to 100 percent as possible. Humidity was maintained by thoroughly wetting down the interior of the chamber from top to bottom for 24 hours prior to inoculation and by operating soaker hoses in the chamber during the inoculation to keep the wood chips on the chamber floor wet. Temperature was maintained close to 15.5 °C (60 °F) by sprinkling the exterior canvas shell continuously during the inoculation run. Temperature and humidity were monitored by a hygrothermograph placed among the flats of seedlings in the chamber.

Artificial inoculation of the whitebark pine seedlings was scheduled in late summer of the third growing season, when teliospore development on the alternate host was at a maximum. Inoculations began in September 2001, with replications one through four initiated on September 8, 10, 13, and 15, respectively. *Ribes* spp. leaves were randomly placed on screens above the seedlings in the inoculation chamber. Agar-coated microscope slides were placed among the tops of the seedlings to monitor spore drop per cm^2 and percentage germination. When a target spore density of 3,500 to 4,000 spores per cm^2 (22,580 to 25,800 spores per in^2) was reached, leaves were removed from the seedlings. Seedlings were left in the chamber for 48 hours following completion of the inoculation before being returned to the greenhouse. Misting was discontinued at this time to allow seedlings to dehumidify gradually and improve the chances of successful infection of the seedlings by the germinating basidiospores. *Ribes* spp. leaves release basiodospores that germinate and enter needles through the stomates the same day. Needle spots are the first symptom of blister rust infection and are normally visible in a month or two. Later, mycelia move through the plant to the stem and a canker becomes visible in a year to 18 months after inoculation. The seedlings were watered and cultured to maintain health and vigor, but no treatments were applied to enhance growth.

Nursery Bed Data Collection of Treatment and Control Seedlings

All seedlings were hardened off and placed in cold storage at –2 °C (28 °F) in October 2001. During May 2002, seedlings were brought out of cold storage and randomly planted in 36-tree plots in four nursery beds corresponding to the four replications. Transplanted seedlings were watered, fertilized, and weeded as necessary for the duration of the rust-resistance testing. Survival, terminal damage, and needle spot presence were collected on each seedling. In addition, the number of needle spots and fascicle length (mm) were collected on one needle fascicle per tree on all inoculated seedlings in the first inspection (June 2002). The second inspection followed a few months later, where survival, terminal damage, needle spot presence, bark reactions, and canker presence were tabulated (September 2002). The third (September 2003) and fourth (September 2004) inspections involved collecting data on survival, terminal damage, bark reactions and canker presence, and total tree height (cm). Similar data in the same sequence were collected on the control seedlings for completeness.

Freeze-Induced Electrolyte Leakage Test

For this portion of the genetics study, needles were collected in March 2005 from a sample of 55 seed sources using both inoculated and control seedlings. These 55 seed sources included the top 10 resistance sources as defined by a 4-trait index score, the 10 most susceptible sources, and 10 mid-level performers. The remaining 25 sources captured both the geographic and elevational range of the study area. The exact same sources do not comprise both the inoculated and control groups due to differential survival; there are 69 unique sources with 41 in common to both the inoculated and control groups.

Six seedlings from each of the four replications were collected per seed source. Necrotic lesions on needles were extremely rare, and such needles were not used in the samples collected. Visible needle condition was quite healthy for both the inoculated and control seedlings sampled.

Sample preparation of needle tissue for the freeze-induced electrolyte leakage test was patterned after Tinus (2002). The calculation of index of injury for each group data set was based on the averaged control data within a group. The first cold hardiness measurements were completed mid-March 2005. The temperature at which needle tissue exhibited 50 percent index of injury was –28 °C (–18 °F). There were no differences among the three elevations sampled. All of the samples were subsequently tested at –28 °C (–18 °F). These tests were used to provide a point estimate of relative mid-winter cold hardiness for each group based on the relative amount of injury sustained at that one temperature. This estimate for a group will hereafter be referred to as cold hardiness.

Statistical Analysis

Descriptive statistics, ANOVA, and Pearson correlation coefficients were determined using SAS® Software (2003). More detailed information on the materials and methods, techniques, and statistical procedures may be obtained from the senior author.

Results and Discussion

First Year Survival (1999)

At this phase of the study, the individual-tree sources were grouped in trays; there was no blocking by sources. Survival ranged from a minimum of 0.4 percent to a maximum of 93.9 percent, with a mean of 37.7 percent and a standard deviation of 23.9 percent. A one-way ANOVA with seedlots as source of variation yielded significant differences ($P < 0.0001$) among sources (n = 108). Poor germination can, in part, be due to cones being collected before the seeds are fully mature. This commonly occurs in the field when cones have not been sampled and cut to confirm the embryo is occupying at least 90 percent of the central cavity. It can also occur when cones are collected too early to avoid bird and animal predation when wire cages haven't been installed over cone-bearing branches.

Third Year Nursery Evaluation (2001)

Prior to subdividing and randomizing sources among blocks, survival, terminal damage, *Fusarium* spp. presence, and height were scored; all variables were significant ($P < 0.0001$) among sources in the one-way ANOVA. Forty-one of the seed sources (7,147 seedlings) were available for analysis of stocktype using the two types of Super Cells. Significant differences were noted both for terminal damage ($P < 0.003$) and height ($P < 0.0001$) among container types (table 2). The third year average height for the Economy Super Cells was 74 mm (2.9 in), whereas the copper-lined Ray Leach Super Cells was 63 mm (2.5 in). The Economy Super Cell yielded larger seedlings (15 percent increase in height) than the copper-lined Super Cell. At this stage of evaluation, a positive effect with the copper-lining may not be demonstrated because whitebark pine is a slower growing species as compared to other conifers. Also, a better sampling design with equal number of seedlings per stocktype would be more beneficial for making future comparisons.

Blister Rust Resistance Evaluation (2002 to 2004)

Rust resistance traits (table 1) were assessed by observation on each seedling (individual tree selection traits) or were based on the performance of all the seedlings belonging to a seed source (family selection traits). Being able to score inoculated whitebark pine seedlings was not taken lightly. Since we were following the model for western white pine (Mahalovich and Dickerson 2004), we were pleased to have a consistent response to blister rust (spotting, canker, and callus [bark reaction]) development. A preliminary screening of the Shoshone National Forest bulked lot (7425) occurred in a western white pine rust screening (2000 to 2002), so a baseline had been established to proceed at a larger scale.

Overall, the percentage rust resistance among the 108 seed sources after the fourth rust screening was 48 percent (table 3). For the purposes of characterizing blister rust resistance rankings among sources, the traits evaluated were needle lesion frequency, early stem symptoms, bark reaction, and canker tolerance. The relative rust resistance ranking was based on a performance index determined among all sources. Seed source ranks were calculated summing the weighted mean for each trait: bark reaction = 4, needle lesion frequency = 3, early stem symptom appearance = 2, and canker tolerance = 1, respectively (Mahalovich 2005). These rankings were then sorted from best to worst within a seed zone (figure 1) and are reported in table 3, as more resistant sources should be favored for cone collections *within* a zone. No-spot, needle shed, and short shoot traits were included in table 3 for completeness, but are not used to characterize blister rust resistance among seed sources.

All block and seed source main effects were significant ($P < 0.0001$) for all rust traits and height in an ANOVA for the inoculated seedlings (n = 108). Similar results were achieved among the control seedlings (n = 92) for survival and height. Whitebark pine has genetic variation for the rust resistance and height traits evaluated. The differences among seed sources are moderately heritable for rust resistance (0.56) and survival (0.64) and highly heritable (0.85) for 6-year height, which can be improved upon in the future through a selective breeding program. At this time, however,

Table 2—Whitebark pine seedling third-year descriptive statistics and significance probabilities (Pr > F) among stock types (2001).

	Ray Leach Economy Super Cell Cone-tainers™ (n = 7007)		Ray Leach Copper-lined Super Cell Cone-tainers™ (n = 140)		
Trait	Mean	Standard deviation	Mean	Standard deviation	Pr > F between stock types
Survival (%)	95.1	21.6	97.9	14.5	0.133
Terminal Damage (%)	0.7	8.3	2.9	16.7	0.003
Fusarium spp. (%)	1.0	9.8	2.1	14.5	0.166
Height (mm)	73.9	27.8	63.1	24.8	<0.0001

Table 3—Whitebark pine seed sources by zone and relative rankings for rust resistance from (best to worst), cold hardiness, and 6-year height performance (all rankings are based on inoculated seedlings, except where noted for control seedlings *). All sources are individual-tree cone collections, except for 7425, which is a bulk collection made up of at least 20 trees.

Source	Zone	National Forest	State	Lat	Long	Elev (ft)	Rust resistance rank	Cold hardiness rank	6-Yr Height rank
452	BTIP	Nez Perce	ID	45.91	115.713	7140	2	5	80
450	BTIP	Nez Perce	ID	45.91	115.713	7140	10	40	42
644	BTIP	Clearwater	ID	46.302	114.608	7400	11		32
424	BTIP	Salmon	ID	45.468	114.291	7860	21	35	16
734	BTIP	Nez Perce	ID	45.363	116.505	8000	26		72
408	BTIP	Nez Perce	ID	45.634	115.947	8200	35.5		33.5
412	BTIP	Nez Perce	ID	45.634	115.947	8200	37	31	84
336	BTIP	Nez Perce	ID	45.378	116.484	8000	41		101
469	BTIP	Nez Perce	ID	45.706	114.998	8200	42	41	25
643	BTIP	Clearwater	ID	46.302	114.608	7400	49	24	94
739	BTIP	Nez Perce	ID	45.363	116.505	8000	54.5	37*	70
473	BTIP	Nez Perce	ID	45.706	114.998	8200	57.5		86
472	BTIP	Nez Perce	ID	45.706	114.998	8200	64	14	47
505	BTIP	Nez Perce	ID	45.378	116.505	8000	68		92
425	BTIP	Salmon	ID	45.468	114.291	7860	76		103
587	CFLP	Clearwater	ID	46.635	114.859	7200	3	3	81
588	CFLP	Clearwater	ID	46.635	114.859	7200	5	15	51
312	CFLP	Kootenai	MT	47.652	115.74	5650	6	42	57
301	CFLP	Kootenai	MT	47.652	115.74	5650	7	47	27
251	CFLP	Idaho Panhandle	ID	46.999	116.027	5940	13	21	107
589	CFLP	Clearwater	ID	46.635	114.859	7200	18		55
584	CFLP	Clearwater	ID	46.635	114.859	7200	19.5	6*	37
248	CFLP	Idaho Panhandle	ID	47.188	116.048	5880	19.5		54
252	CFLP	Idaho Panhandle	ID	47.014	116.027	5920	25		11
635	CFLP	Clearwater	ID	46.563	114.442	7300	30	10	13
303	CFLP	Kootenai	MT	47.652	115.74	5650	32		48
655	CFLP	Clearwater	ID	46.534	115.004	7000	34		77
630	CFLP	Clearwater	ID	46.563	114.442	7300	43		40
257	CFLP	Idaho Panhandle	ID	46.999	116.027	5800	60.5		79
255	CFLP	Idaho Panhandle	ID	47.014	116.027	5920	63	52	95
637	CFLP	Clearwater	ID	46.563	114.442	7300	78		73
631	CFLP	Clearwater	ID	46.563	114.442	7300	98	38	28
215	CLMT	Deerlodge	MT	46.388	112.191	7600	15		63
69	CLMT	Beaverhead	MT	45.154	113.549	8400	17		49
56	CLMT	Beaverhead	MT	45.154	113.549	8400	29		30
34	CLMT	Beaverhead	MT	45.154	113.549	8400	45.5		19
420	CLMT	Bitterroot	MT	45.72	113.994	8270	56		38
502	CLMT	Bitterroot	MT	46.068	113.801	8040	57.5	17	35
464	CLMT	Bitterroot	MT	46.507	114.224	6470	65		18
26	CLMT	Beaverhead	MT	45.938	113.512	7900	71		2
498	CLMT	Bitterroot	MT	46.068	113.801	8040	72	17*	61
500	CLMT	Bitterroot	MT	46.068	113.801	8040	81	26	75
48	CLMT	Beaverhead	MT	45.154	113.549	8400	83		83
422	CLMT	Bitterroot	MT	45.72	113.994	8270	89	19	24
460	CLMT	Bitterroot	MT	46.507	114.224	6470	99	18	59
535	CLMT	Beaverhead	MT	45.705	112.925	8000	102	4	85
52	CLMT	Beaverhead	MT	45.153	113.549	8400	103	28	97
78	GYGT	Beaverhead	MT	44.818	111.873	8800	47		76
517	GYGT	Targhee	ID	44.554	111.428	8350	52	12	88
7425	GYGT	Shoshone	WY	43.512	109.839	9800	59	16*	58
549	GYGT	Gallatin	MT	45.4	111.279	8600	66	13	60
32	GYGT	Beaverhead	MT	44.818	111.873	8800	73		56
547	GYGT	Gallatin	MT	45.4	111.279	8600	77	2*	52

Continued on next page

Table 3—Continued

Source	Zone	National Forest	State	Lat	Long	Elev (ft)	Rust resistance rank	Cold hardiness rank	6-Yr Height rank
543	GYGT	Gallatin	MT	45.4	111.279	8600	79	22*	45
111	GYGT	Custer	MT	45.042	109.43	8900	80	33	104
95	GYGT	Custer	MT	45.042	109.43	8900	82		50
89	GYGT	Custer	MT	45.042	109.451	9200	84		91
523	GYGT	Gallatin	MT	45.269	111.424	9000	85	11	64
74	GYGT	Custer	MT	45.042	109.451	9200	87		53
512	GYGT	Targhee	ID	44.554	111.428	8350	93	20	78
4	GYGT	Gallatin	MT	45.049	109.95	9600	94		100
546	GYGT	Gallatin	MT	45.4	111.279	8600	100	27	39
530	GYGT	Gallatin	MT	45.269	111.424	9000	104	2	99
41	GYGT	Custer	MT	45.042	109.451	9200	105	9	9
59	GYGT	Custer	MT	45.042	109.555	8900	107	43	68
97	GYGT	Beaverhead	MT	44.818	111.873	8800	108	44	89
663	MSGP	Flathead	MT	48.494	114.341	6000	22		31
270	MSGP	Flathead	MT	48.494	114.341	6000	23		12
676	MSGP	Flathead	MT	48.494	114.341	6000	39		41
669	MSGP	Flathead	MT	48.494	114.341	6000	50		36
271	MSGP	Flathead	MT	48.494	114.341	6000	60.5		69
280	MSGP	Flathead	MT	48.884	114.507	6000	69.5	22	46
267	MSGP	Flathead	MT	48.494	114.341	6500	69.5	29	67
71	MSGP	Lewis & Clark	MT	47.516	112.797	7600	74		14
382	MSGP	Lolo	MT	47.014	114.009	7860	75	39	43
679	MSGP	Flathead	MT	48.884	114.485	6450	88		15
378	MSGP	Lolo	MT	47.014	114.009	7860	90.5		74
85	MSGP	Lewis & Clark	MT	47.835	112.807	7500	92		98
289	SKCS	Colville	WA	48.969	117.109	6800	1	7	102
609	SKCS	Idaho Panhandle	ID	48.379	116.187	6370	4	51	22
340	SKCS	Colville	WA	48.881	117.242	6480	8	46	66
376	SKCS	Lolo	MT	47.014	114.009	7860	9	25	65
481	SKCS	Lolo	MT	47.16	115.249	7050	12		1
690	SKCS	Idaho Panhandle	ID	46.171	116.735	5430	14		23
496	SKCS	Lolo	MT	47.086	114.576	7420	16		105
612	SKCS	Idaho Panhandle	ID	48.379	116.187	6370	24		71
594	SKCS	Lolo	MT	47.522	115.699	6150	27	49	29
337	SKCS	Idaho Panhandle	ID	48.826	116.599	6800	28		17
627	SKCS	Idaho Panhandle	ID	48.84	116.512	6700	32	54	20
484	SKCS	Lolo	MT	47.16	115.249	7050	32		9
329	SKCS	Kootenai	MT	47.826	115.385	5650	35.5		8
296	SKCS	Idaho Panhandle	ID	48.855	116.469	5820	38		82
603	SKCS	Idaho Panhandle	ID	48.379	116.187	6370	40	53*	2
595	SKCS	Lolo	MT	47.522	115.699	6150	44		5
440	SKCS	Lolo	MT	47.158	114.366	6960	45.5		87
490	SKCS	Lolo	MT	47.086	114.576	7420	48	6	90
334	SKCS	Kootenai	MT	48.97	115.842	7200	51	48	21
477	SKCS	Lolo	MT	47.16	115.249	7050	53	8	6
297	SKCS	Idaho Panhandle	ID	48.855	116.469	5720	54.5	55	93
623	SKCS	Lolo	MT	47.753	114.85	6140	62	36	10
325	SKCS	Kootenai	MT	47.953	115.556	6000	67	30	7
626	SKCS	Idaho Panhandle	ID	48.84	116.512	6700	86	42*	33.5
314	SKCS	Kootenai	MT	47.826	115.385	5700	90.5	53	3
351	SKCS	Colville	WA	48.707	118.471	7135	95	50	106
480	SKCS	Lolo	MT	47.16	115.249	7050	96	41*	4
434	SKCS	Lolo	MT	47.158	114.366	6960	97	32	44
349	SKCS	Colville	WA	48.707	118.471	7137	101		108
617	SKCS	Lolo	MT	47.753	114.85	6140	106	45	26

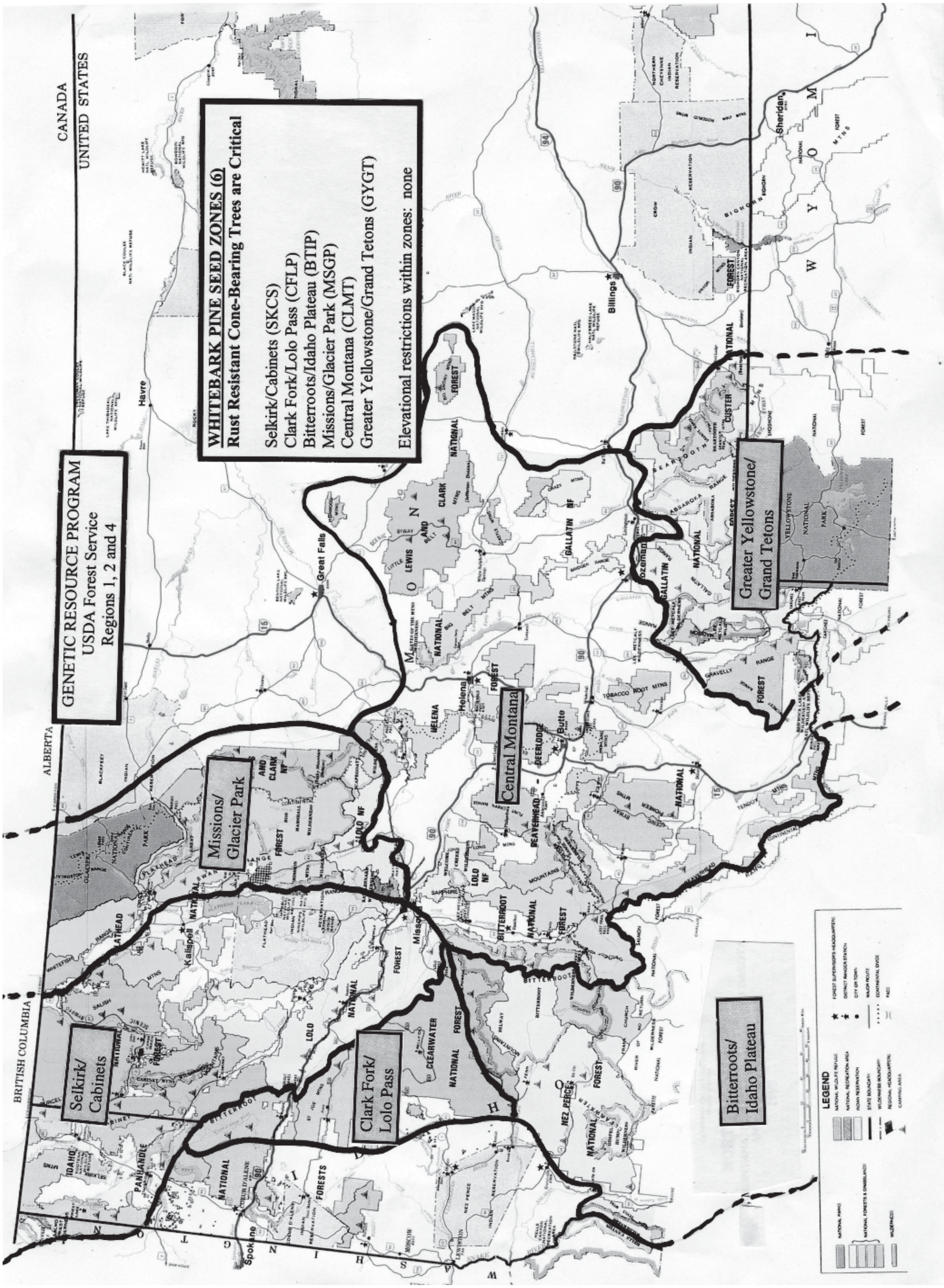

Figure 1—Whitebark pine seed zones for the Northern Rockies.

there are no plans for a breeding program in whitebark pine (Mahalovich and Dickerson 2004); current plans are to work on the selection and testing (rust screenings) and establishing small-scale seed orchards (about 1.5 ac [0.6 ha] in size). The height rankings found in table 3 were derived from the inoculated seedlings. Overall, blister rust resistance increases from southeast to northwest (figure 2).

Cold Hardiness (2005)

Prior to measuring the index of injury for each seed source, a control line (benchmark) at 50 percent injury was established. This benchmark was consistent among both inoculated and control seedlings and across a sample of low, moderate, and high elevation sources, so there was no difference in the amount of leakage other than from freezing. Only seed source as a main effect (n = 55) was significant ($P < 0.0001$) for index of injury in an ANOVA for the inoculated seedlings; blocks were not significant. The differences among seed sources were moderately heritable for cold hardiness (0.50). Both block and seed sources as main effects were significant ($P < 0.0001$) for index of injury in an ANOVA for the control seedlings. There was a slight difference among seedling types; in other words, blister rust appears to have impacted needle tissue hardiness. The cold hardiness ranking for the inoculated seedlings ranged from 50.8 to 81.3. The cold hardiness range for the control seedlings was 38.3 to 76.6. Overall, the control seedlings were more cold hardy than inoculated seedlings (average score of 58 versus 63). We anticipate providing more absolute values and a more detailed assessment. Focusing on seed sources for cone collections, relative rankings of cold hardiness among the 55 samples are found in table 3 (lower scores are more cold-hardy). These measurements used to determine cold hardiness rankings are point estimates sampled in late winter. Additional work is recommended to determine if late winter/early spring cold hardiness is more critical for whitebark pine, as in western larch (*Larix occidentalis*) (Rehfeldt 1995) or if late summer/early fall cold hardiness is a more important adaptive measure, as in Douglas-fir (*Pseudotsuga menziesii*) (Rehfeldt 1979).

Trait Correlations

Early in the whitebark seedling's life, there does not appear to be a physiological trade-off between allocating resources for rust resistance at the expense of growth; however, trees with more rust resistance are slightly less cold hardy, although not statistically significant. Height has an unfavorable and weak correlation with cold hardiness (taller seedlings have a larger index of injury). Taller trees are more rust resistant and are *slightly* less cold hardy.

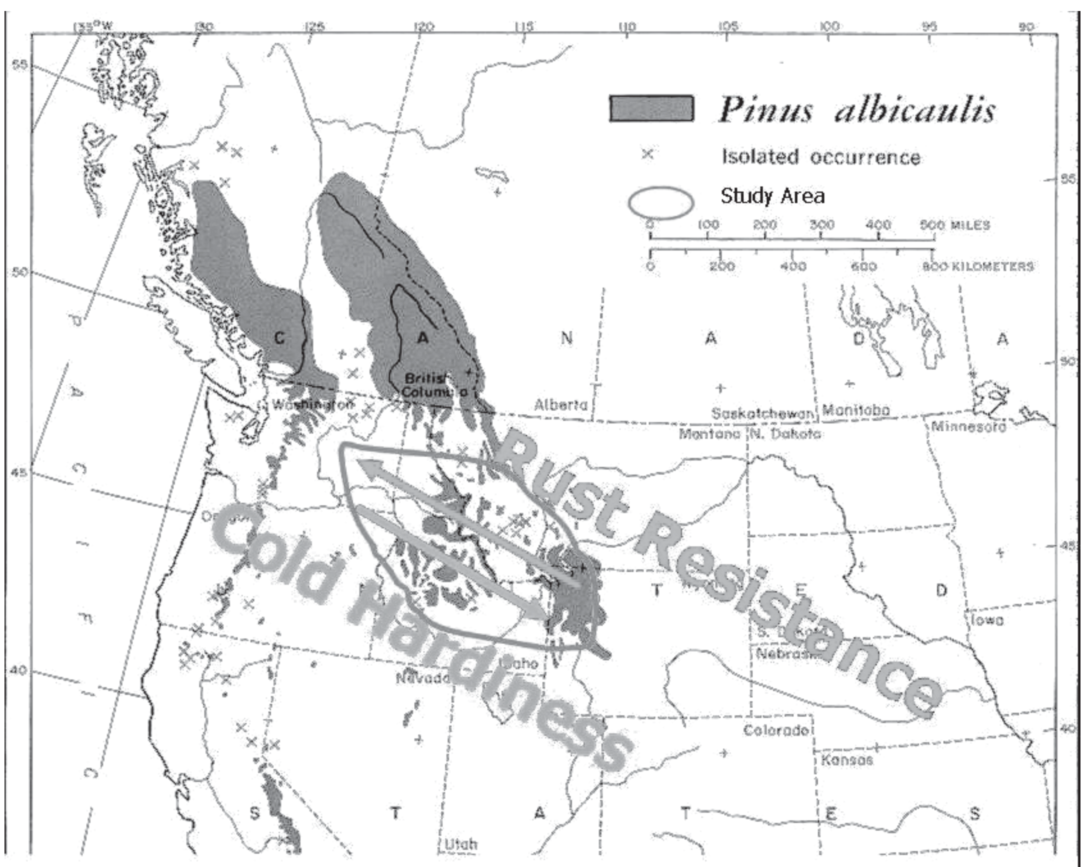

Figure 2—Whitebark pine study area and relationship of blister rust resistance to late winter cold hardiness.

These correlations can be managed by choosing seed sources within a seed zone that possess both desirable rust resistance and cold hardiness levels. Unfavorable correlations can also be handled in designing breeding zones and choosing selection methods in tree improvement programs that mediate these opposing trends. Even though cold hardiness decreases from southeast to northwest (figure 2), not all seed sources have poor rust resistance; for example, source 587 (Clearwater National Forest, seed zone CFLP), source 452 (Nez Perce National Forest, seed zone BTIP), and the number one rust resistant source 289 (Colville National Forest, seed zone SKCS) are relatively cold-hardy even though they are in the northwest portion of the region (table 3).

WBP Planting Strategies For Restoration

It is possible to proceed with immediate restoration and wildlife habitat improvement through planting since we have identified both rust resistant and cold hardy seed sources within six of the seed zones studied. A summary of the key findings is presented in the following planting recommendations:

1) Choose rust resistant sources within a seed zone (table 3).

2) Ensure that cone collections have a minimum of 20 cone-bearing trees separated by 200 ft (61 m) in distance to minimize any negative effects of inbreeding.

3) There are no elevation restrictions on seed transfer within a seed zone.

4) When blister rust infection levels vary within a zone, seeds collected for immediate rehabilitation efforts should not be moved from areas with low (<49 percent) to moderate (50 to 70 percent) infection levels to outplanting sites with higher infection levels (>70 percent) (Mahalovich and Dickerson 2004). Seeds collected from phenotypically resistant trees in areas with high infection levels are suitable for outplanting on sites with low, moderate, or high infection levels (Mahalovich and Hoff 2000).

5) The top three resistant seed sources per seed zone should be considered an effective cone collection strategy for a 10-year planning window. The next 10-year planning period should focus on a minimum of three *new* collection areas in order to broaden the genetic base used in outplanting programs over time. This assumes that the USDA Forest Service Northern and Intermountain Regions Whitebark Pine Genetic Restoration Project achieves stable funding to proceed with rust screening of the additional 650 plus trees described in Mahalovich and Dickerson (2004).

6) When selecting stocktypes, there appears to be no advantage to using copper-lined containers.

7) When planting in swales or frost pockets, choose cold-hardy sources that are rust resistant (table 3).

8) Field monitoring of outplanted whitebark pine seedlings shows a favorable advantage to providing a microsite regardless of slope, aspect, swales, or frost pocket conditions. We recommend planting seedlings next to stumps, logs (figure 3), and, if none are available, use rocks (figure 4) or shade cloths. Note in figure 3 the relative heights of the shorter seedling outplanted in the open, the mid-sized seedling near a log, and the tallest seedling adjacent to the downed log. The microsite is reminiscent of Clark's nutcracker who cache seeds near the base of trees, roots, logs, rocks, plants, or in cracks and fissures in trees and logs (McCaughey and Tomback 2001). The microsite is thought to provide shade and increased soil moisture retention during early establishment.

Figure 3—Microsite example using logs next to planted whitebark pine seedlings on the Clearwater National Forest (Bob Grubb, Forest Tree Improvement Coordinator and Lenore Seed Orchard Manager in photo).

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Figure 4—Microsite example using a rock next to a planted whitebark pine seedling on the Caribou-Targhee National Forest.

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What's New With Nurseries and Reforestation Projects at the Missoula Technology and Development Center

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Abstract: The USDA Forest Service Missoula Technology and Development Center (MTDC) offers technical expertise, technology transfer, and new equipment development to Federal, State, and private forest nurseries. Current and recently completed projects at MTDC include a nursery soil moisture meter, remote data collection systems, low cost weather stations, electronic soil penetrometers, reforestation toolbox Web site, shielded herbicide sprayer, synthetic fabrics to wrap seedlings, Styroblock™ sterilizer, whitebark pine seed scarifier, improved forbs seed harvester brushes, economic fencing to exclude wildlife from sensitive areas, and a cuttings preparation saw.

Keywords: nursery equipment, whitebark pine, sterilizing equipment, soil compaction, herbicide, electric fencing

Introduction

Missoula (MTDC) and San Dimas (SDTDC) Technology and Development Centers help solve problems identified by field employees of the USDA Forest Service. For 60 years, MTDC and SDTDC have been evaluating existing technology and equipment, developing equipment prototypes, and conducting technology transfer through their reports, Web sites, videos, and DVDs.

The reforestation and nurseries program is located at MTDC in Missoula, Montana. The principle focus of the nurseries program is to develop new equipment or technology to improve nursery operations and processes. The program is sponsored and funded by the USDA Forest Service Forest Management staff group at the Washington Office and through State and Private Forestry.

Our focus is on applied technology and technology transfer. We do not conduct research, but sometimes we apply research findings to help solve on-the-ground problems.

Projects typically last from 2 to 4 years depending on their complexity. Equipment-based projects are field tested and fabrication drawings are made so the equipment can be duplicated by other nurseries. We document our projects through printed reports or journal articles that are available from MTDC. You can find our drawings and reports on our Web site: http://www.fs.fed.us/eng/t-d.php

Following are some current nursery projects that may be of interest to you.

Nursery Soil Moisture Meter

Recognizing the need for fast, accurate soil moisture readings, MTDC was asked to evaluate portable electronic moisture measuring devices to see if such instruments were an alternative to the oven-drying method many nurseries use. Project Leader Ted Etter found that the Campbell Scientific TDR (time domain reflectometry) probe, model CSI-616, looked the most promising.

A formula converts electronic TDR signals to volumetric soil moisture content. However, Ted thinks that the "one size fits all" formula is not accurate enough for nursery work. He is looking into the feasibility of developing more accurate formulas customized to reflect soil characteristics at individual nurseries. We have lab tested the probes to determine the effects of soil variables on the TDR readings. Ted is currently validating the formulas he has developed with field tests at several nurseries in the Northwest. Until he completes these evaluations, the jury is still out as to whether these instruments will be accurate enough or user-friendly enough to replace the current soil bake-and-weigh method.

Remote Data Collection Systems

Project Leader Gary Kees is evaluating remote sensors that can be monitored via satellite that will tell silviculturists when distant sites are ready for planting (figure 1). We have purchased three AXTracker satellite systems and the necessary ground probes. The AXTracker is a satellite transmitter originally developed to track vehicles, remote facility alarms, broken pipelines, and so on. MTDC set out remote sensors to determine when sites are ready for planting. Sensors were placed at ground level and just below ground level at a remote planting site on the Boise National Forest. We were able to tell when the snow had melted by observing the sensor temperatures on a Web site. Project Leader Gary Kees estimates a cost of about U.S. $1,000 to monitor a site, including the cost of the AXTracker and sensors (Kees and Trent 2005).

Low-Cost Weather Stations

Measuring weather at project locations is of interest to researchers, incident managers, and to anyone who needs to keep track of site-specific weather conditions. MTDC is evaluating low-cost weather instruments that have data logger capabilities. We purchased three different systems for U.S. $800 to U.S. $1300 and evaluated them. Project Leader Gary Kees believes that these less expensive systems are good alternatives in specific applications to the more sophisticated RAWS weather stations that cost closer to U.S. $15,000. It may also be possible to tie these weather stations into the AXTracker satellite system in order to monitor the readings remotely. A report should be completed in 2005 documenting the findings.

Figure 1—AXTracker satellite transmitters can be used to monitor remote conditions such as temperature, facility intrusions, or track vehicles if coupled with GPS.

Soil Compaction Tester

MTDC evaluated three electronic soil penetrometers (Rimik CP-40, Field Scout SC90, Eijkelkamp Penetrologer) on the Shasta-Trinity and Boise National Forests. This new generation of electronic penetrometers shows promise for many forestry soil applications as measured by soil strength. The penetrometers gave inconsistent results for tree contract inspections and are not recommended for that purpose. The electronic penetrometers give consistent results for measuring soil compaction in other situations, are easy to use, and collect data that can be stored for later downloading and use. The cost for the penetrometers we tested ranged from U.S. $1,500 to U.S. $5,200. We also tested a mechanical Compacto-Gage to see how it compared with the electronic instruments. Project Leader Gary Kees plans to document his findings and the availability of this new generation of soil penetrometers in 2005.

Shielded Herbicide Sprayer

Weeds are difficult to control in hardwood nursery beds. Chemicals such as Roundup™ kill the weeds, but also kill the seedlings if the spray is misdirected. Several nurseries have fabricated shielded sprayers to prevent herbicides from being applied to the hardwood seedlings. MTDC reviewed this existing equipment, selected the best features, and incorporated those features into a new prototype model.

Project leader Keith Windell developed a prototype spraying system, had it fabricated, and field tested it in May 2002. The MTDC prototype sprayer is mounted on a 3-point tractor hitch. It is a fully contained system with up to nine nozzles. The shields are adjustable, and the sprayer can be steered for perfect alignment as it is pulled down the rows. The spray pump is run off the tractor's power take-off and is calibrated before spraying.

Field testing was done at the Virginia Department of Forestry New Kent and Augusta Nurseries. Some deficiencies became evident. MTDC modified the sprayer to correct the problems by redesigning the steering, adding height gauge wheels, and adding a more precise hood width adjustment (figure 2). The Virginia nurseries retested the sprayer and found that it works well. MTDC has construction drawings, available upon request, for the improved prototype, and plans to document the findings in 2005.

Figure 2—An improved shielded herbicide sprayer, developed by MTDC, was evaluated in Virginia.

Seedling Wrap

Jelly-rolling bareroot seedlings in wet burlap is a traditional way to protect and carry seedlings in planting bags just prior to planting. Over the past several years, many National Forests have used a synthetic fabric, Kimtex®, as an alternative to burlap. Kimtex® is no longer available in the sizes needed for tree wrapping, so we were asked to find another fabric that would work.

The Bitterroot and Idaho Panhandle National Forests evaluated several synthetic fabrics in 2004. DuPont Sontara™ absorbent fabric worked the best, and MTDC located a supplier, American Supply Corporation, that agreed to custom cut the fabric into 22-in (56-cm) wide rolls, 200-yd (183-m) long, for tree wrapping applications (Vachowski 2005).

Container Sterilizer

MTDC has looked at methods and equipment to sterilize used Styroblock™ containers before filling them with medium and sowing seeds. Certain pathogens like *Pythium* spp. and *Fusarium* spp. remain in the residual soil and in some roots that may remain after the seedlings have been extracted from the Styroblock™ containers.

Currently, many nurseries dip their used containers into hot vats of water (160 to 180 °F [71 to 82 °C]) and hold them there for 1 to 2 minutes. This method works, but is slow and labor intensive.

Project Leader Andy Trent evaluated steam heat, like that in a sauna, and found that it will effectively sterilize the blocks. The concept is that a large room could be constructed where pallet loads of blocks could be treated at one time. The blocks could be left in the oven for a specific period of time and then removed. We procured a boiler and steam distribution system and built an operational production-sized system at USDA Forest Service Lucky Peak Nursery. The room is a 24-ft by 47-ft by 10-ft high (7.3-m by14.3-m by 3-m high) converted cooler that holds up to 4,000 Styroblock™ containers. A propane boiler (figure 3) produces steam for the room at 160 °F (71 °C). After 6 hours at 160 °F, tests showed that *Fusarium* spp. levels were reduced from 90 to 5 percent. Eighty percent of the blocks had no fungal growth after treatment. Cost to heat the room was about U.S. $3.00 per hour, and total installation cost was about U.S. $24,000 (Trent and others 2005).

Figure 3—This propane boiler supplies 160 °F (71 °C) steam to a 24-ft by 47-ft by 10-ft high (7.3-m by 14.3-m by 3-m high) room used to sterilize used Styroblock™ containers at USDA Forest Service Lucky Peak Nursery, Idaho.

Whitebark Pine Seed Scarifier

Whitebark pine is being outplanted for restoration projects because its seeds are an important food source for grizzly bears. Scarifying the seed coat increases germination dramatically at the nursery, from about 1 to 2 percent natural germination to more than 60 percent germination if there is a 1-mm cut in the seed coat. Currently, each seed is being cut manually with an Exacto knife, a tedious process that presents its own set of safety concerns.

MTDC has developed a machine that may replace the Exacto knife operation. Our first attempt produced a sophisticated instrument that uses a laser-guided rotary-head cutting tool to make a 1-mm cut through the seed coat The prototype worked in limited testing, but was not adaptable enough to the large variability found in later seedlots.

We developed a less complex prototype, which consists of sandpaper-lined cans that rotate in an orbiting pattern. Karen Burr at the USDA Forest Service Coeur d'Alene Nursery evaluated the machine to see if it improved germination. She found that after 180 minutes of sanding, germination is similar to the results gained by individually nicking seeds by hand. Germination doubled over doing no treatment except stratification. Fabrication drawings are available from MTDC. Andy Trent is project leader.

Reforestation Toolbox

Field reforestation skills and knowledge are being lost as people retire. MTDC was asked to pull some of this knowledge together on a Web-based series of training modules for reforestation. The result is a work in progress, called the Reforestation Toolbox.

So far, Project Leader Andy Trent has developed content for four sections: planting tools, planting techniques, handling, and contract inspections. Cone collection, site preparation, field handling, and hardwoods sections are not completed. Forest Service reforestation specialists Glenda Scott and Duane Nelson are providing content for the site. Before publicizing the Web site, Andy is planning to have it peer reviewed.

Animal Management Economic Fencing

The project assigned to Project Leader Gary Kees was to look for low-cost methods for excluding wildlife from plantations, riparian areas, and aspen stands.

The systems were to be removable and reusable after 3–5 years and must stand up to wildlife and heavy snow.

The project is complete. Gary installed two types of electric fence (polyrope and high-tensile, figure 4) and one type of nonelectric polymesh fence around willow patch and aspen regeneration areas and monitored them over two winters. The polymesh fence held up well in a moose exclosure. Of the electric fences, the high-tensile electric fence held up very well in severe climatic conditions on the Continental Divide in Montana. The polyrope electric fence sagged initially, but stabilized over time and worked well once it was retightened. The fences effectively excluded moose and elk, but were not evaluated in areas of high deer concentrations. We also installed a high-tech monitoring system for the electric fences—one that transmitted signals to a satellite—so the results could be monitored on a Web site. Initially the monitoring system was not dependable, but performance improved to the point that it is now working as the test continues (Kees 2004).

Mechanical Forbs Seed Harvester

Clark Fleege, manager of the USDA Forest Service Lucky Peak Nursery, asked MTDC to develop and test a prototype mechanical forbs seed harvester at Lucky Peak Nursery. Too many seeds were lost using their Woodland Flail Vac. Instead of developing a new machine, Project Leader Gary Kees has developed four different brush configurations to try on the Woodland Flail Vac. The replacement brushes cost about U.S. $500 per set, and have stiffer brushes with convoluted wafers (figure 5). In limited testing at Lucky Peak on wild geranium (*Geranium maculatum*) and Arizona

Figure 4—MTDC evaluated nonelectric polymesh fence, polyrope electric fence, and high-tensile electric fence to exclude moose and elk from restoration areas.

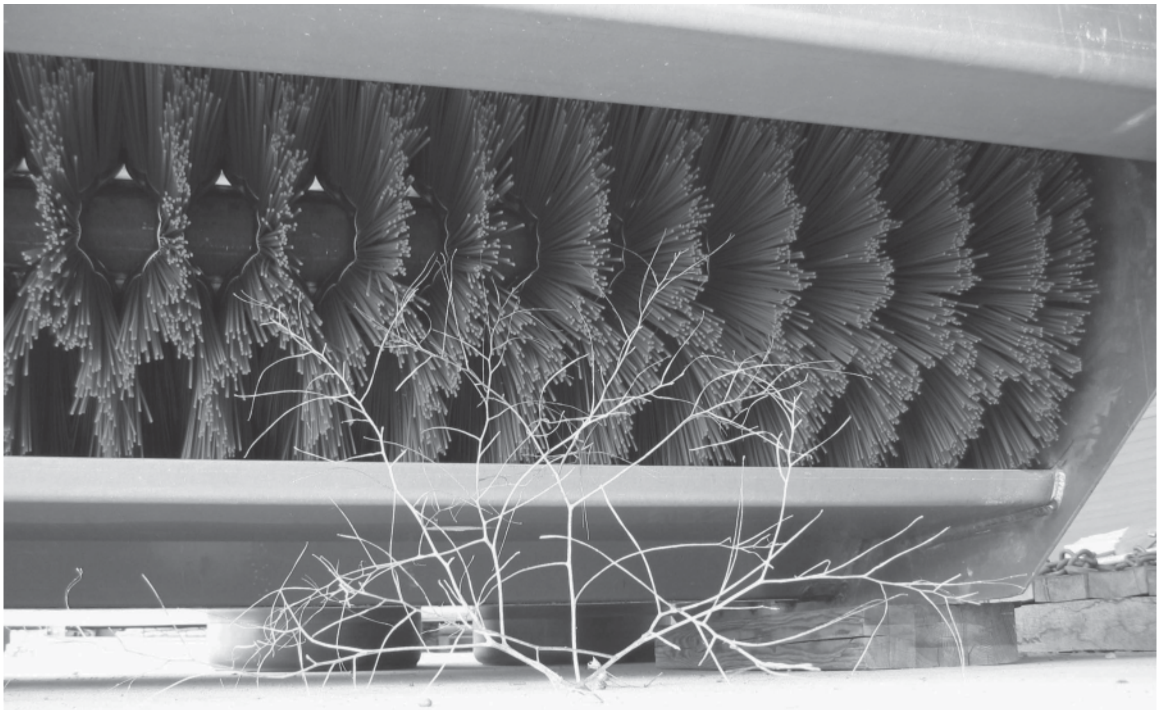

Figure 5—Stiff bristles with convoluted wafers worked better than factory brushes to collect small forbs seeds on this Woodland Flail Vac brush harvester.

fescue (*Festuca arizonica*), the new brushes collected significantly more seeds than the original brushes.

Hardwood Cuttings Preparation Equipment

MTDC was asked to develop equipment to prepare hardwood cuttings for planting. The current practice at many nurseries is to cut long whips from stumps, then use table saws to cut the whips into 6- to 8-in (15- to 20-cm) cuttings. This work is time consuming and raises safety concerns because of the close proximity of the operator's hands to the saw.

Project leader Gary Kees developed a prototype saw that made the job of preparing the cuttings easier and safer. The electric miter saw has a brake that stops the blade once the cut is made and a foot-operated clamp that holds a bundle of whips as they are cut. The saw was tested at the Bessey Nursery in Halsey, NE, early in 2003, and drawings and a report are available from the MTDC.

For More Information

A complete listing of the nurseries projects completed over many years is available electronically to Forest Service and BLM employees at the MTDC intranet site, http://fsweb.mtdc.wo.fs.fed.us/programs/ref/. Drawings and reports that are available in electronic form are available to the public at http://www.fs.fed.us/eng/t-d.php.

Paper copies of MTDC reports and drawings are available from:

USDA Forest Service, MTDC
Attn: Publications
5785 Highway 10 West
Missoula, MT 59808
Phone: (406) 329-3978
Fax: (406) 329-3719

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Northeastern Forest and Conservation Nursery Association Meeting

Springfield, Missouri

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Growing Shrubs at the George O. White State Forest Nursery: What Has Worked and What Has Not

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Keywords: native species, shrubs, bareroot, riparian restoration, wildlife restoration

Introduction

At the George O. White State Forest Nursery in Licking, MO, we annually grow about 20 species of shrubs. That number has been larger in some years. For most species, we purchase seeds locally and process them at our nursery. Our shrubs are used for wetland restoration, windbreaks, visual screens, riparian buffers, and wildlife plantings.

Sales of shrubs continue to be high, and we sell out of most species every year. Even during years of sluggish sales in conifers or hardwood trees, our shrub demand tends to remain high. Since 2001, we have had about 5.8 million shrubs available for purchase and have sold 5.3 million, or about 91 percent of the inventory.

So what have we learned? We have great success with some species, but have not been so successful with others. We have, however, learned better ways of getting the seedlings we need.

Shrub Species Grown at the George O. White Nursery

Dogwood (*Cornus* spp.)

We grow five species of dogwood, including flowering (*C. florida*), roughleaf (*C. drummondii*), red-osier (*Cornus sericea*), gray (*C. racemosa*), and silky (*C. oblique*) dogwood. The dogwoods are the first seeds we sow in the fall, with a target planting date of October 1 if possible. Over the years, we have also found that dogwood seeds store very well. Last year we sowed the last of our 1988 collection of flowering dogwood seeds and we were still getting very good germination and seedling growth. The reason that we still had 1988 seed available is that I rarely plant all seeds from one source and year. I sow seeds like this with nearly every species we grow, for both large trees and shrubs. We may plant 100 lb (45 kg) of flowering dogwood seeds in a year, and these seeds will come from three to five sources from at least that many different years. Much of our flowering dogwood is locally collected, so the source may be local, but the year collected is different. This helps to avoid total disasters.

Flowering Dogwood—Flowering dogwood is the hardest of the dogwoods to grow, and the seeds are the most expensive. We get more complaints when we are sold out of this species than about anything else we grow, and we get more complaints about survival. The seedlings store and outplant poorly. During the growing season, this species is the slowest growing of the dogwoods, and powdery mildew is a constant problem. About 200 lb (91 kg) of nitrogen (N) are applied each summer to get the seedlings to 12 in (30 cm) or greater in size, and we treat seedlings with fungicide on a 7- to 10-day schedule. But we sell over 100,000 every year—year in year out—so we keep growing it!

Gray Dogwood—Gray dogwood is not nearly as difficult to grow or handle as flowering dogwood. We have found that it likewise takes about 200 lb (91 kg) of N per year to get them to 12 in (30 cm) in height. They are faster growing than flowering dogwood, but not by much. We spray them on the same fungicide schedule as flowering dogwood, but I am not so sure that it is necessary.

Roughleaf, Red-Osier, and Silky Dogwood—The other three dogwoods are very different than growing flowering and gray dogwood. These require less than half the nitrogen (N), and all three of these dogwoods usually reach 24 to 36 in (61 to 91 cm) in height with little effort. In addition, they do not require as much or any fungicide as flowering or gray dogwood. All three species store very well for months in cold storage, and we almost never have any complaints about survival.

Smooth Sumac (*Rhus glabra*)

Smooth sumac is a mildly popular species. We only grow about 25,000 per year. Some years we sell most of the seedlings, but now and then we have some left. I really only grow it because, when I took over the nursery, we had about 300 lb (136 kg) of clean seeds in cold storage that had been collected in the mid 1980s. We sow about 20 lb (9 kg) per year, so my replacement will be growing it for years after I am gone! We do not sow this species until about the first week of June. If it is planted any earlier, it gets really big. We treat the seeds for 60 minutes in H_2SO_4 prior to sowing. This same routine for seed treatment and sowing time has also worked for shining sumac (*R. copallina*).

Buttonbush (*Cephalanthus occidentalis*)

Buttonbush is a new species for us that we only began to grow about 3 years ago. Missouri Department of Conservation Fisheries and Wildlife Divisions wanted us to add more wetland species, and this is one we added. Customer requests for this species have been good, but the learning curve on growing this was steep. Our first crop yielded 275 seedlings from 4 lb (2 kg) of seeds. The next year we got 44,000 seedlings from 4 lb (1.8 kg) of seed. We now plant buttonbush the same time and the same way we do river birch (*Betula nigra*) and sycamore (*Platanus* spp.). We lay the seeds on top of the ground, press it in, and then cover it with hydromulch—no sawdust. We then water it twice per day until it germinates. This is another of those shrubs that can get huge in one growing season—3 ft (0.9 m) or more.

Blackberry (*Rubus* spp.)

We sell about 100,000 blackberry seedlings each year—if we can get that many. It is somewhat tricky to grow, I think. We plant this species the first week of July to give it warm, then cold stratification. It germinates in early April of the following year. It must be planted very shallow and allowed to sit for almost a year before germination. It seems that we get 5,000 to 100,000 seedlings from year to year with the same seedlot. Our wildlife folks are really pushing this species for quail management, so the demand will stay high. Our shippers, including United Parcel Service (UPS) and the United States Postal Service (USPS), do not much care for these plants sticking out the tops of the bundles, so they have to be top clipped. Workers don't care much for this species either.

Deciduous Holly (*Ilex deciduas*)

We purchase and clean all seeds that we use for deciduous holly, which are very slow to germinate. We sow this species in late September and it does not germinate until April, a year and 7 months later. There does not appear to be any way to get these seeds to germinate any earlier. This is a slow growing species that requires about 200 lb (91 kg) of N each year to get the seedling to 12 in (31 cm) or greater in height. We have found this species to store somewhat poorly, so we lift it as we need it.

Redbud (*Cercis canadensis*)

Redbud is one of the easiest seedlings to grow. We give the seed a 30-minute soak in H_2SO_4, and sow it in the first or second week of May. This is another species that gets very big. Seedlings cold store very well.

Hazelnut (*Corylus americana*)

Another very popular species is hazelnut, selling out every year even if we grow 125,000 or more plants. Hazelnut is one of the most costly seedlings we grow. We buy all seeds locally starting in mid-August. The seeds are in green husks. Thousands of pounds of husked seeds are spread out on screens for about 2 months. (Stir occasionally!) A large amount of mold is generated on the husks, but seed quality does not seem to be affected. Seeds continue to ripen in the husks, so it can be picked green. We run the dried husks through our HA400 brush machine to remove the husks. Clean seeds are sown in mid- to late October. Two years ago we were able to purchase more seeds than needed (usually we cannot buy enough), so we stored about 500 lb (227 kg) for a year. Seeds were placed in plastic bags in seed cans and stored at 34 °F (1 °C) for a year. The germination was great on our 1-year-old seeds. We have excess seeds in storage now. Because the seed crop of hazelnuts for this year appears to be poor, this 2004 seed will be great to have in storage.

Wild Plum (*Prunus* spp.)

Wild plum is so easy to grow. We sow seeds in mid-October and it is one of the first trees to germinate the following spring. Late frosts don't bother it a bit. At our nursery, it is about 15 in (38 cm) tall by mid May. It does not require much fertilizer or irrigation, and may need only minimal treatment for leaf diseases. We lift a bunch of tall seedlings in fall. Seedlings store great for months in cold storage, and customers love it. We sell upwards of 125,000 to 150,000 seedlings per year. We buy all plum seeds locally.

We used to sell this as *P. americana*, but there are six species of wild plum native to the county where our nursery is located and we have seeds of all these species brought in. So we no longer call it *P. americana*, but just *Prunus* spp.

Aromatic Sumac (*Rhus aromatica*)

Sumac is another very popular species for us. We sell 100,000 or more seedlings per year, if we have the stock. This is another fall-planted species. Typically we treat our sumac seeds with H_2SO_4 for 30 minutes and then sow it late October. Several years ago I decided, because the seeds are sown in the fall, to not bother with acid treatment. Here is one you can take home. We sow 20 lb (9 kg) of seeds per year. The year we did not treat with acid, we got less than 30,000 seedlings out of the 20 lb. In each of the last 5 years we did treat with acid, we have averaged over 95,000 seedlings per year. All sowings were done with the same seedlot. Treat it with acid! One word of caution, if you do treat with acid, wait until warm fall weather is over. In 1999, I planted this species in late September. We had a wet, warm October and the first week of November quite a bit of this germinated. It did fine for a week or so, but then it got down to about 15 °F (–9 °C) one night—the rest is history.

Washington Hawthorn (*Crataegus phaenopyrum*)

Hawthorn is another species that is fairly easy to grow, but somewhat slow growing. We have found that it requires 150 to 200 lb (68 to 91 kg) N fertilizer to reach a 12-in (30-cm) seedling. Occasional problems with leafhoppers slow the growth. This is another species that we have planted in early October one year and had the seeds germinate and die in November. So we wait until late October to sow this species.

Ninebark (*Physocarpus opulifolius*)

Ninebark is getting to be another of our big sellers. It is a great plant for dry soils, wet soils, windbreaks, wildlife cover, and visual screens. We plant about 3.5 to 4.5 lb (1.6 to 2.0 kg) of seeds for about 50,000 to 60,000 seedlings. We plant in late October. This is another species where depth is critical when sowing. It is such a small seed that, if sown too deep, you get a terrible stand. The seeds need to be laid on the surface of the bed, pressed, and lightly covered with sawdust.

Chokecherry (*Prunus virginiana*)

Chokecherry is a fairly new species in our mix. It has not caught on well with our customers. Maybe it is the name? It is easy to grow and is sown in the fall. The seeds germinate quickly in the spring and seedlings need very little fertilizer to exceed 12 in (30 cm) in height. There is, however, a leaf disease that once you get it, the seedlings stop growing. No matter how much you treat with fungicide, the seedlings will not resume growing. We have already had 30,000 in the seedbeds and 25,000 are about 6 in (15 cm) tall in October. We now treat on a 7- to 10-day fungicide treatment schedule.

Witch Hazel (*Hamamelis vernalis*)

We collect all of our own seeds for witch hazel locally, and it is the most fun of all of our seeds. The collectors must pick the seeds before they are ripe. We spread the seedpods on screens and then completely cover the screens with plastic. These seeds explode out of the pods when ripe. You can stand in our seed building when we have these seeds drying and it sounds like someone is making popcorn. Even with all the plastic, we find witch hazel seeds in every corner of the building. It can be sown in early or late fall. I have sown it at the end of September with no problems. It is slow growing, and takes a lot of water and fertilizer to get this species up to 10 in (25 cm) in height. So just a word of advice—don't plant it next to your plum!

Buckbrush (*Symphoricarpos orbiculatus*)

Yes, we grow buckbrush. I inherited large amounts of seeds and when those seeds are finally gone, we will quit growing this species. We sow in the first week of July along with the blackberry. Powdery mildew can be a problem. We typically only have approximately 15,000 seedlings to sell each year and usually sell most or all of them.

False Indigo (*Amorpha fruticosa*)

We started growing false indigo about 5 years ago. We quit growing the nonnative shrub lespedeza (*Lespediza* spp.), and this was a legume to replace it. This is becoming very popular with our customers because it survives everything. We have had customers tell us they outplanted a bunch of trees and everything died except the indigo; not one of the false indigo died. In fact, I don't think I have ever heard anyone say they had one die. It flowers in the second growing season and produces lots of seeds. Our wildlife folks like it for quail plantings. The first year we grew this species, we sowed in the spring after acid treatment and got an excellent stand. In the years since, we sowed in the fall with no seed treatment. We were no longer getting decent stands and I blamed the seeds. Last fall, we sowed 10 lb (4.5 kg) of a seedlot and it barely came up. So we took an additional 10 lb out of the same seedlot, treated it for 8 minutes in H_2SO_4 and we have an awesome stand. Another take home message is to sow this species in the spring after acid treatment.

Spicebush (*Lindera benzoin*)

Another new species on our list is spicebush. We have only been growing this species for about 3 years. I liked it because it will tolerate a lot of shade, has lots of berries for wildlife, and has good fall color. Sales of this species have not been what I had hoped. We buy all of our seeds locally, but seeds can be difficult. We have dried the berries and cleaned the berries. Either method works well, but the seeds store poorly. If you grow this species, count on getting fresh seeds each fall for the best stands.

Elderberry (*Sambucus canadensis*)

Elderberry is our "newest" species. This is only our second year of growing this species, and last year we only had about 20,000 plants. We sold out in about 3 weeks and spent the rest of the season listening to people gripe about us being sold out. This year, we should have 30,000 to 40,000 seedlings, so we will see if people still want it. Elderberry is great for wildlife plantings. We sow in the fall, and the seeds are sown at a very shallow depth. The seedlings do get big in one year. In our one year of experience, they seem to store very well. In fact, by early spring they started leafing out in the cooler!

Hazel Alder (*Alnus serrulata*)

Our fisheries folks asked me to grow hazel alder for riparian plantings. We have tried twice. We collected the seeds ourselves and sowed it according to the seed manual and got zero seedlings. We then bought some seeds and sowed them but got zero seedlings. So this species is on hold for now. I am open to suggestions.

Other Species

On occasion we grow other shrub species. This is often done because someone gave us some seeds or requested that we grow some for a special project.

We currently have some Ohio buckeye (*Aesculus glabra*) and red buckeye (*A. pavia*), the latter of which is a great tree. Red buckeye grows much faster than Ohio buckeye, is more colorful, and tolerates lots of shade. However, the seeds are hard to come by. We also grow some white fringetree (*Chionanthus virginicus*), which is a beautiful small tree, but takes about 3 years to get from sowing to 12 in (30 cm) seedling. We have grown corkwood (*Leitneria floridana*)—listed as an endangered species with the Federal government—for a restoration project on our lands. We will try just about anything once!

I have no doubt that shrubs will continue to be in demand for us. There are many new cost share programs in which landowners only plant shrubs. So we will continue to grow these species and may add a few more over the next few years.

The USDA Forest Service National Seed Laboratory

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Keywords: seed testing, germ plasm, tree improvement, gene conservation, technology transfer

Introduction

The USDA Forest Service National Seed Laboratory has provided seed technology services to the forest and conservation seed and nursery industry for more than 50 years. This paper briefly traces the lab's evolution from a regional facility concerned principally with southern pines to its newest mission as a national facility working with all native U.S. plants and serving national and international needs.

History

Civilian Conservation Corps (CCC) camps operated forest tree nurseries to supply trees to their own reforestation crews. Philip C. Wakely of the USDA Forest Service Southern Research Station in New Orleans conducted germination tests of the seeds used in those CCC nurseries in the south. This early effort to evaluate the seeds sown in the nursery demonstrated to nursery managers in the south the benefits of a seed laboratory. Knowing how well the seeds would germinate removed a great deal of the uncertainty in producing a crop of seedlings. Testing by the Southern Research Station stopped with the outbreak of WWII and the end of the CCC. The effort was revived in 1952 at the USDA Forest Service Ashe Nursery in Brooklyn, Mississippi. In 1953, the testing service was offered to all nurseries in the southern region. During these first two testing seasons (fall 1952 through spring 1954), the lab was called the Ashe Nursery Seed Laboratory.

In 1954, the lab was moved to the Georgia Forestry Center near Macon, GA, and began testing services that November. This move was made in cooperation with the Georgia Forestry Commission (GFC) who had a strong need for seed work. The GFC provided a building, business support services, and a technician. Under this arrangement, more nurseries were encouraged to use the laboratory because testing fees were set in advance and not determined on a prorated basis at the end of the season. The 1954 fiscal year laboratory report states that Federal fiscal regulations made advanced prediction of testing fees impossible. With the move to Georgia, the laboratory name was changed to the Region 8 Seed Testing Laboratory to reflect the region-wide mission. Seed testing occupied approximately half the work year from fall to early spring. The balance of the year was spent on seed research. By fiscal year 1956, this research was formally supported by the Georgia Forest Research Council, another agency of the State of Georgia, and supervised by the USDA Forest Service Southeastern Forest Experiment Station.

Early Growth

In spring 1957, the seed laboratory building was expanded to accommodate more testing. By 1958, a totally new building was needed to meet the needs of the soil bank program, which was converting marginal farm land into forests, and other programs working to reforest millions of acres of abandoned farmland across the south. The number of tests was now exceeding 1,000 per year at a cost of U.S. $9.87 per test. (Compare that price to U.S. $54 per test in 2005.) Over 20 species per year were tested, mostly conifer. Test samples began to come from the northern parts of the eastern U.S. In recognition of this widening area of service, the lab was renamed the Eastern Tree Seed Laboratory in 1961. The expanded facilities met the needs of the program until the late 1970s. The laboratory had engaged in technical assistance with western nurseries, which led them to submit test samples in significant numbers. The seed exchange program with international forest researchers that had been added to the lab in 1972 was also growing. Hundreds of seedlots were being sent out of the country in support of research efforts. New services for evaluating seed orchard management also added a large number of seed tests. The lab was physically too small for the amount of work to be done. With these expanded efforts, the lab had clearly reached a major developmental stage.

Emergence of a National Laboratory

With the program now at a national and international level, the name was changed to the National Tree Seed Laboratory in 1979. A major program review conducted in 1980 led to national funding for the lab by the USDA Forest Service, with the National Forest System, Research and Development, and State and Private Forestry each contributing one-third of the budget. Seed testing receipts remained a significant source of revenue. In light of the importance of the national and international components of the program, the State of Georgia felt the program had reached a point were it could no longer legitimately provide financial support. Therefore, they stopped providing business support functions, technicians for the lab, and research funding. Desiring to maintain the long-term cooperation with the USDA Forest Service, the State leased the existing building and some land to the Forest Service for 99 years for the much needed modernization and expansion of the laboratory. The formal mission was now to provide seed testing services in forestry, to serve as a Federal standard to resolve seed testing disputes among non-Federal labs, to supply research seed samples to other countries, and to serve as a center for seed technology support to State, private, and Federal forestry organizations.

The Widening Need

The main focus through the 1980s was still on conifer species. The Conservation Reserve Program was requiring historically high numbers of pine seedlings to restore highly erodible farm lands back to forests. In 1988, 3.4 million ac (1.4 million ha) were reforested, which was the largest tree planting program in U.S. history. Two billion seedlings were required that year, and the Flint River Nursery in Georgia set a record by lifting and packing 1 million trees in a single day. Timber programs on the National Forests were large and required many conifer seedlings to reforest harvested lands. However, by 1990, habitat restoration was becoming a broader issue. Conifer seedlings were no longer enough. Previously less-favored species, such as longleaf pine (*Pinus palustris*) and hardwoods, were in growing demand. Endangered plants, grasses, and forbs were receiving increased attention in conservation efforts. The term native plant became increasingly important as society tried to retrieve a fast disappearing heritage and confront a growing menace of exotic invasive plants. Some State nurseries were converting part or most of their production into native grass and forb production. Private nurseries were formed to do the same. In response to these changes, the seed lab began to develop expertise with nontimber native plants. At the same time, much of the original mission of making conifer seedling production successful had been accomplished. Although ongoing work with conifers had to be continued and improvements made, the needs of society were changing. By the end of the decade, the seed lab was again at a crossroads.

Beginning in 2003, the mission of the National Tree Seed Laboratory was reviewed with a hard look into the future. Both public and private sectors of the conservation and forest nursery industry were involved in this review process. The findings of the review were basically that the previous needs of nurseries still existed, but the broader range of plants now needed and used in conservation work required a broader mission for the lab. Many seed issues blocked the use of nontimber native plants. However, the half century of applying and developing seed technology for timber trees had well prepared the lab to solve these seed problems and train the new personnel that were involved in the new era. The native nontimber species had all the same problems of seed dormancy, seed zoning, periodic seed production, and seed cleaning that the timber species have. The skill sets and basic technologies were in place to do the job. The end result of the review process was the Chief of the Forest Service announcing a new mission for the lab in June 2005.

The 2005 Mission

The new mission included many of the elements of the old mission: seed testing services for nurseries and seed dealers, international seed exchange for research, technology development, technology transfer, and training. These elements now applied to all native plants, not just trees. To reflect the inclusion of all native plants, the word Tree was removed from the name in order to be inclusive. The USDA Forest Service National Seed Laboratory (NSL) emerged as the newest iteration of the lab. One very exciting new dimension was added, which was long term seed storage for preserving genetic resources. Each of these mission elements is described in more detail in the following paragraphs.

Seed Testing Services

Seed testing is the fee-for-service work that began in the 1950s and has become an integral part of the forest and conservation seed and nursery industry. Customers are located throughout the country and come from all ownership types. Tests provided are germination, purity, seed weight (for example, seeds per pound), seed moisture content, X-ray analysis, tetrazolium tests, and excised embryo tests. The latter two tests are quick tests of viability used predominately for species with deep and variable dormancies for which germination is impractical. This service is the backbone of most other services, as all others involve some sort of seed analysis work. It also provides the laboratory and nursery/seed personnel around the country with a direct link in daily operations, which in turn opens up close communications for technology transfer and technical assistance work. The laboratory views this service as very important in establishing and maintaining a cooperative and integrated relationship with those who are served. The NSL is the only U.S. laboratory that is accredited by the International Seed Testing Association to test forest seeds. The number of clients served and the number of seed samples received in the 50 plus years of service testing exceeds 300 and 60,000 respectively. In the very near future, clients will be able to interact with the seed lab over the internet to receive test results almost as rapidly as they are completed.

Technology Development

Seed collection, cleaning, testing, and storage protocols are desperately needed for nontimber native plants. Therefore, the lab is running as many trials as possible to assist in this effort. Germination trials with and without light, with and without stratification, and at differing temperatures will lead to at least initial germination prescriptions and, eventually, Association of Official Seed Analysts rules for some species. An extensive collection of seed cleaning equipment at the lab allows for rapid development of cleaning protocols. Storage studies, by their very nature, will take more time to complete. In general, dry seeds will likely be found to store well in freezing temperatures; testing the species for desiccation tolerance will, therefore, be the first step. Work will also continue with tree species as needed.

Technology Assistance and Training

Any time there is a seed problem, the laboratory staff is available by phone, e-mail, U.S. mail, fax, or onsite visit. A Web site at http://www.nsl.fs.fed.us provides contact information and many useful references on seeds and the services available from the lab. Workshops are provided several times per year on a full range of seed topics. These workshops are small groups, not to exceed 20 to 25 persons, and are largely hands-on and tailored to meet the needs of the attendees.

Gene Conservation

This service is a major expansion of the laboratory mission. Long term seed storage requires totally pure seeds of high viability. Its maintenance requires seed testing facilities. Therefore, this work is a very natural companion to the developmental work on native plant protocols performed at the lab and the seed testing services. Seeds are not stored for 100 years for some abstract value. Therefore, collections will be made available for research, both domestically and internationally, as much as possible. This is a logical extension of the work done to this point through the seed bank to meet research requests from outside the country. A cooperative agreement has been signed between the Forest Service (FS) and the Agricultural Research Service National Center for Genetic Resource Preservation (NCGRP) at Fort Collins, Colorado. The Forest Service will receive seeds from FS units and FS cooperators, test the seeds, package the seeds, and send them to NCGRP for storage in their disaster proof vaults. The different types of materials currently envisioned to enter into the program are presented in the next section.

Categories of germ plasm collections (table 1).

- Threatened, sensitive, and endangered species. Threatened, sensitive, and endangered species were identified as highest priority to enter into the collections because these could be totally lost in the wild. Stored seeds could be used to replace lost populations.
- Forest health collections. When a species is fast being lost from the landscape due to an insect or disease infestation, it would be wise to make seed collections in advance of the epidemic to have materials to work with in subsequent restoration efforts. Current examples are white pine blister rust (*Cronartium ribicola*) in whitebark pine (*Pinus albicaulis*), emerald ash borer (*Agrilus planipennis*) in all native ash (*Fraxinus* spp.) species, and woolly adelgid (*Adelges tsugae*) in hemlocks (*Tsuga* spp.).
- Early tree improvement selections. As tree improvement programs advance, it becomes more difficult and costly to maintain clone banks of early selections. Some collections are lost or are threatened with loss as programs end and personnel retire. These collections, however, represent substantial financial, scientific, and intellectual investments. Seeds and tissues of these early selections could economically be stored in the NCGRP. These resources would then be available to check past historical work, renew programs that were temporary halted, take breeding programs in new directions without redoing the original work, or be able to take programs in new directions that would have been lost as the process of selection and domestication progress.
- Provenance collections. The geographic genetic variation of many forbs, grasses, shrubs, and hardwood tree species have not been adequately studied. Work is beginning with many species under varying initiatives. The collection of seeds is expensive and time consuming. Portions of the samples gathered for provenance and common garden studies could be preserved for future reference and study. This would allow for continuity among subsequent studies of a given species and facilitate additional work as resources and opportunities become available.
- Fine hardwoods. Fine hardwoods are those that bring premium prices for lumber and veneer and are very important in manufacturing high value-added products such as furniture, paneling, and flooring. They usually require sites of highest quality and, therefore, are often in competition with agriculture or housing developments for space. Additionally they are under heavy harvest pressures because of their value. These factors together threaten the amount of genetic variation available to researchers for expanding and preserving this valuable economic resource.

Table 1—Eligibility of seedlots for distribution and routine monitoring.

Type of collection	For distribution	Monitor viability
Threatened, sensitive, and endangered	No	No
Forest health	Yes	Yes
Tree improvement	No	No
Provenance/common garden	Yes	Yes
Fine hardwoods	Yes	Yes
Small populations	No	Yes
Special	Determined case by case	Determined case by case

- Small populations. Many major tree species that are not, on the whole, threatened do have small unique populations included in their geographic range. Longleaf pine in the State of Virginia has few natural trees left. Logging, naval stores industry, and agriculture have almost eliminated the species at its most northern extremes. Sitka spruce (*Picea sitchensis*) in the Puget Sound area has been greatly reduced in numbers due to housing developments. Yet this is a valuable seed source for plantings not only in that area but also in Europe. These marginalized populations represent unique germ plasm and would be worth preserving.
- Special collections. Without doubt there will be collections that do not fit into the above categories. These, for now, will be placed in the category of special collections.

Conclusion

Every 20 to 25 years, a major evolution has occurred at the USDA Forest Service National Seed Laboratory. All steps have been in direct response to the conservation challenges of the day. The current changes at the NSL are the most recent actions to meet the needs of the 21st century and beyond.

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Basamid® G for Weed Control in Forest Tree Nurseries

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Abstract: Basamid® G is a granular soil fumigant containing dazomet, which has activity on weeds, insects, nematodes, and diseases. Basamid® G was compared to methyl bromide:chloropicrin and was equally effective as a weed control material in forest tree nurseries. Pine and hardwood plantings were treated with both materials in replicated and nonreplicated trials with various weed species, and both fumigants were highly effective. The recommended rate for Basamid® G is 350 to 530 lb/ac (390 to 595 kg/ha), and plant-back interval for tree seeds is 14 to 28 days. These may vary slightly due to local environmental conditions (rainfall, soil type, percentage organic matter, available soil moisture). Basamid® G gives the grower an alternative to methyl bromide, which has equal efficacy and grower-friendly application procedures. Basamid® G is halogen free with no ozone depleting components and will give the nursery grower effective, easily applied, and environmentally safe weed control for the future.

Keywords: dazomet, MITC gas, soil fumigant, methyl bromide alternative

Introduction

In 2003, Kanesho Soil Treatment (a joint venture between Agro-Kanesho Co., Ltd. and Mitsui and Company, Ltd.) acquired several soil disinfestation products from BASF Corporation, including Basamid® G granular soil fumigant, which contains the active ingredient dazomet. Certis USA, a wholly-owned subsidiary of Mitsui and Company, has assumed marketing and development responsibility for Basamid® G in the United States and Mexico.

Unlike most other fumigants, Basamid® G (dazomet) is inactive until it comes in contact with soil moisture and decomposes to release methylisothio-cyanate (MITC) gas. MITC gas diffuses through the air spaces between soil particles, killing soil-dwelling organisms such as weeds, nematodes, insects, and fungi. MITC gas breaks down into safe soil nutrients with no halogen or ozone depleting components. Basamid® G can be user-applied without the extensive equipment, containment, and safety requirements of other soil fumigants and has no detrimental impact on the environment. Plastic tarping is not required, although it may improve fumigation performance in some cases.

Basamid® G has been in use outside the United States for over 20 years, most extensively in Japan and Europe. It is registered in the United States for control of weeds, nematodes, and diseases, and has been used in forest tree nurseries for the production of pine and broadleaf seedlings since the early 1990s. The fumigant is easily applied by nursery staff on their own schedule, with no need to cover the field with plastic. A clean start can be achieved for a new seedling crop without the logistical challenges of custom application or disposal of used plastic tarps.

A power tiller is the preferred method for incorporating Basamid® G. A well prepared seedbed with a moisture content of at least 50 percent of field capacity is necessary. The power tiller incorporates Basamid® G to an 8 to 10 in (20 to 25 cm) depth after it is metered onto the soil surface from a Gandy® type spreader. A roller towed behind the tiller compacts the soil to seal in MITC gas. Overhead irrigation should be applied immediately after incorporation and for 7 days to further seal the MITC gas in the soil. One inch (2.5 cm) of irrigation water should be applied the first day to wet the soil to a depth of 6 to 8 in (15 to 20 cm) to seal the soil and release the MITC gas. On the second day, 0.5 to 0.75 in (1.3 to 1.9 cm) of water should be applied, with 0.25 to 0.5 in (0.6 to 1.3 cm) applied on subsequent days to maintain the soil seal and contain the gas. The soil should be allowed to dry out after 7 days to release the MITC gas. To test for the presence of MITC gas, a sample of the soil from the surface to 6 in (15 cm) deep can be taken and placed in a sealed Mason jar with moistened lettuce seeds. If the seeds germinate, the gas has dissipated. A light soil aeration will speed the release of gas if planting is to be made within 14 to 28 days of Basamid® G application.

Our objective in the nursery trials was to determine the effectiveness of Basamid® G for control of weeds in pine and broadleaf plantings. Comparisons with methyl bromide and untreated plots were made where possible.

Materials and Methods

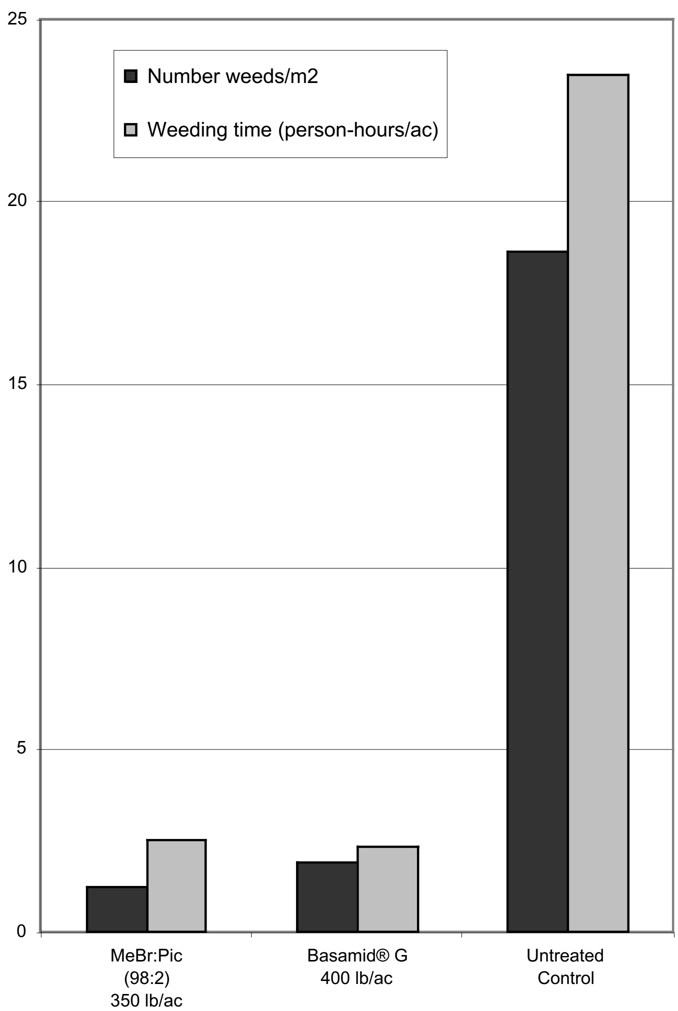
The field trials took place in 2004 to 2005 on tree nurseries in South Carolina, Georgia, and Missouri. All Basamid® G plots were applied by a power tiller with a modified Gandy® spreader attached to meter the granules in front of the tiller. Soil temperatures were 65 to 75 °F (18 to 24 °C) and soil moisture was 50 to 60 percent. A roller was pulled behind the tiller to seal the soil surface. Water was applied through overhead irrigation for 7 days beginning immediately after application at rates of 1 in (2.5 cm) on day 1, 0.5 in (1.3 cm) on day 2, and 0.25 in (0.6 cm) on the remaining 5 days. Post emergent herbicides were applied throughout the trial period as part of the standard weed control programs at the nurseries. Plots were hand-weeded as necessary during the summer of 2005, and data was collected to include person-hours of weeding and weight or number of weeds. Randomly selected square meter blocks from each plot were taken for weed counts in the South Carolina and Missouri trials. All three plots were used in the Georgia trial. Primary weed species for each site were recorded.

Basamid® G rates were 400 lb/ac (450 kg/ha) in the South Carolina and Missouri trials and 490 lb/ac (550 kg/ha) in the Georgia trial. The methyl bromide used in all trials was 98:2 methyl bromide:chloropicrin at 350 lb/ac (390 kg/ha).

All plots were fall-fumigated well in advance of planting and allowed to remain idle until bed formation and seed planting in spring of 2005. Winter annual weeds were controlled by postemergent herbicidesas, as needed, before planting .

Results and Discussion

The trial in South Carolina by MeadWestvaco was a large plot nonreplicated trial planted with loblolly pine (*Pinus taeda*). Basamid® G (400 lb/ac [450 kg/ha]) was an effective weed control and equivalent to methyl bromide (350 lb/ac [390 kg/ha]) in numbers of weeds per square meter and weeding times per acre (figure 1). Both treatments were much more effective than the untreated control.



- Nonreplicated field trial.
- Individual plots 0.25 to 0.33 ac (0.10 to 0.13 ha).
- Sandy soil not fumigated for 2 years.
- Basamid® G applied 10/12/04; methyl bromide applied 10/04.
- Water seal maintained for 7 days by overhead irrigation.
- Plots weeded in June 2005.
- Major weeds included carpetweed, pusley, and hardwoods.
- Goal® herbicide applied as needed during the year.

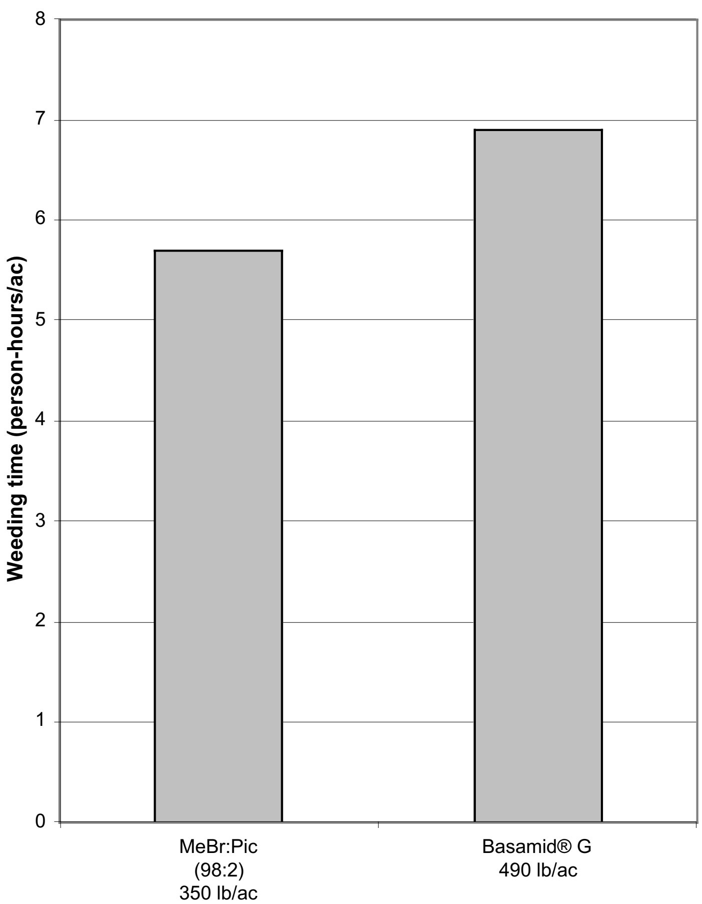
Figure 1—Weed control with Basamid® G in the MeadWestaco forest tree nursery, 2004 to 2005 (1 lb/ac = 1.1 kg/ha).

Rayonier, Incorporated in Georgia installed a field trial with three replications in a randomized complete block design comparing methyl bromide (350 lb/ac [390 kg/ha]) and Basamid® G (490 lb/ac [550 kg/ha]) planted with loblolly and slash pine (*P. elliottii*) in alternating rows. Weeding time in person-hours per acre was slightly higher in the Basamid® G plots, but overall weed control was similar and acceptable to the grower (figure 2). Six rows of the methyl bromide plots did not receive post-emergent herbicides and these were omitted from the comparison.

A large plot nonreplicated trial was installed by George O. White Nursery in Licking, MO. Two broadleaf species were planted in this trial. Pin oak (*Quercus palustris*) was planted in the methyl bromide treated plot and pecan (*Carya illinoensis*) in the Basamid® G treated plot. Weeding times were similar in both plots but the Basamid® G treated plot had more weeds per square meter (figure 3). This may be due to the closed canopy and large size of the pin oak (methyl bromide) and the open canopy and much smaller size of the pecan (Basamid® G). The nurseryman considered the weed control by both fumigants to be effective.

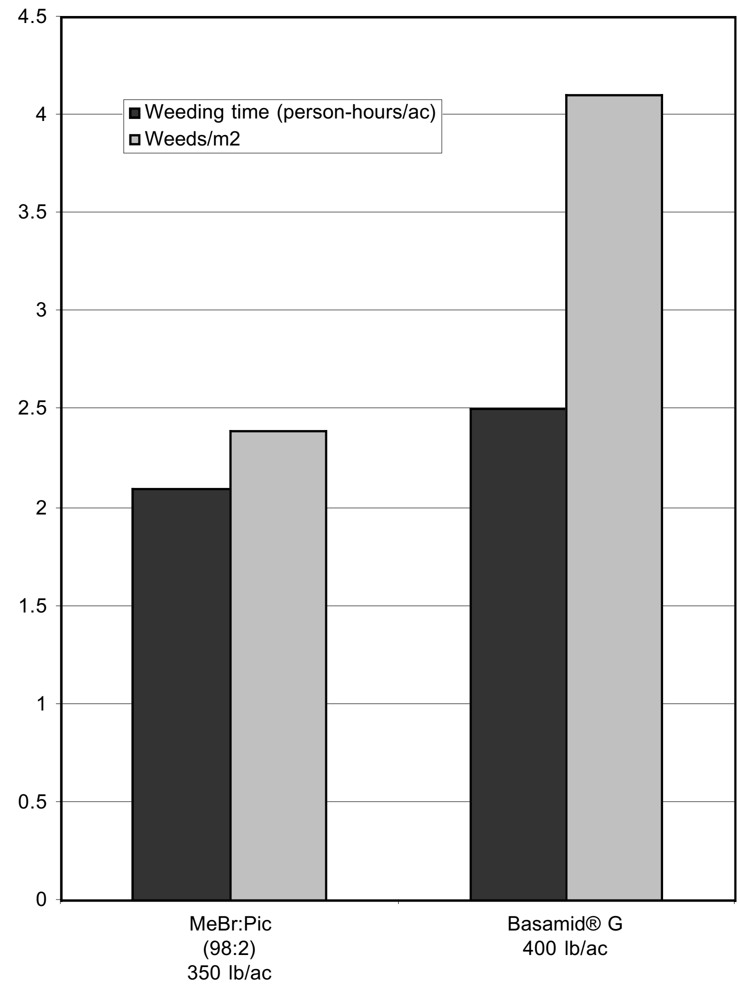
Summary

Basamid® G has been successfully used in forest tree nurseries for the production of pine and broadleaf seedlings since the early 1990s and has efficacy equal to methyl bromide. Field trials in several States have shown that Basamid® G is highly acceptable to the nursery growers and is applicator and environmentally friendly. Basamid® G is easily applied by nursery staff on their own schedule with no need to cover the field with plastic. Maintaining a water seal for 7 days is critical for successful weed control. To further assure effective weed control, soil moisture should be maintained at optimum levels for 1 to 3 weeks prior to Basamid® G application to allow for seed and nutsedge germination. If application is necessary within 14 to 28 days of planting, be sure that all MITC gas is out of the soil before planting by using the lettuce seed germination test. Light aeration of the soil will remove the soil crust and help remove residual MITC gas. MITC gas contains no halogens and no primary or secondary ozone depleting components. Do not apply Basamid® G to dry or improperly tilled soil. Do not apply within 3 to 4 ft (0.9 to 1.2 m) of growing plants or within the dripline of trees. Do not use Basamid® G when soil temperatures are below 43 °F (6 °C) or if ambient air temperature is 103 °F (39 °C) or above.



- Randomized complete block, 3 replications.
- Sandy loam soil, not fumigated for 2 years.
- 1.4 ac (0.57 ha) Basamid® G treated, 0.95 ac (0.38 ha) methyl bromide treated.
- Basamid® G applied 11/19/04, methyl bromide applied spring 2005.
- Water seal maintained for 7 days by overhead irrigation
- Plots weeded summer 2005.
- Major weeds included morning glory and coffee bean.
- Glyphosate, Prowl®, and Goal® applied as needed during the year.

Figure 2—Weed control with Basamid® G in the Rayonier, Incorporated forest tree nursery, 2004 to 2005 (1 lb/ac = 1.1 kg/ha).



- Nonreplicated field trial.
- Large individual plots 1.2 ac (0.5 ha).
- Clay loam soil, not fumigated for 2 years.
- Basamid® G and methyl bromide applied 9/21/04.
- Water seal maintained for 7 days by overhead irrigation.
- Plots hand weeded summer 2005.
- Major weeds included wild mustard and lespedeza.
- Glyphosate, Prowl®, and Goal® applied as needed during the year.

Figure 3—Weed control with Basamid® G in the George O. White Nursery, 2004 to 2005 (1 lb/ac = 1.1 kg/ha).

Survival and Growth of Container and Bareroot Shortleaf Pine Seedlings in Missouri

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Abstract: Shortleaf pine (*Pinus echinata* Mill.) seeds collected from several half-sib families were grown as both container and bareroot stock and outplanted in two tests at the George O White Nursery in Licking, Missouri. After eight growing seasons, 2-year-old container seedlings had significantly better survival than 2-year-old bareroot seedlings, while survival of the 1-year stocktypes was not significantly different. Two-year-old container seedlings had 52 percent higher survival than 2-year-old bareroot stock. Two-year-old bareroot seedlings had greater stem diameter and volume growth than the 2-year-old container seedlings, but the two stocktypes were not significantly different in height. One-year-old stocktypes did not perform significantly different in all growth traits.

Keywords: shortleaf pine, *Pinus echinata*, container seedlings, bareroot seedlings, Missouri

Introduction

All shortleaf pine (*Pinus echinata* Mill.) planting stock produced in Missouri, with the small exception of seedlings produced for a recent progeny test, are grown in bareroot nurseries. Bareroot seedlings are generally inexpensive to produce, store, and transport, but may be susceptible to summer droughts. All eight open pollinated progeny tests established between 1980 and 1983 in Missouri, except one test established in 1982, had poor survival (<40 percent) due to severe summer heat and drought. It is likely that restoration and progeny testing of shortleaf pine in the dry and harsh sites in Missouri Ozarks could be improved by outplanting seedlings produced in containers. Many studies have shown that container stock survives and grows better than bareroot stock, particularly on adverse or marginal sites, for shortleaf pine (Brissette and Barnett 1992; Barnett and Brissette 2004), and other related species such as longleaf pine (*P. palustris*) (Amidon and others 1982; Boyer 1989) and loblolly pine (*P. taeda*) (South and Barnett 1986). For example, in a 5-year comparison of longleaf bareroot and container plantings in Georgia, Boyer (1989) found that container stock averaged 76 percent survival and 6 ft (1.8 m) in height compared to 51 percent survival and 4.9 ft (1.5 m) in height for bareroot stock. The improved survival and growth are generally attributed to root systems of container seedlings remaining intact during lifting while roots of bareroot seedlings can be severely damaged (Barnett and Brissette 1986). Because roots of container seedlings are less disturbed during lifting, they experience less transplant shock or adjustment than bareroot seedlings. Outplanting of container stock is now accepted as the most successful method for regenerating longleaf pine (Barnett and McGilvray 1997).

The first objective of the study was to compare survival and growth of bareroot and container-grown shortleaf pine seedlings. The second objective of the study was to provide a genetic evaluation of the parents and use this information for thinning the Ouachita National Forest clonal seed orchard at Mt. Ida, AR. The third objective was to estimate genetic parameters and to use these parameters to predict genetic gain. This study addresses the first objective. The hypotheses are: 1) container seedlings will have higher survival; 2) container seedlings will have greater growth than bareroot seedlings; and 3) 2-year-old container seedlings will have much higher survival and greater growth over the 2-year-old bareroot seedlings compared to 1-year-old container seedlings over the 1-year-old bareroot seedlings.

Materials and Methods

Planting Stock and Seedling Production

Planting stock being tested in this study were 1- and 2-year-old bareroot and container-grown seedlings of shortleaf pine. Both stocktypes were raised at George O. White State Forest Nursery in Licking, MO. Seeds were collected from 50 half-sib families from the clonal seed orchard in Ouachita National Forest in Arkansas. This grafted seed orchard was established in 1969 to 1971 and consisted of 50 parents collected throughout the natural range of shortleaf pine in the Mark Twain National Forest in Missouri.

The 1- and 2-year-old container stocks were grown in Ray Leach Cone-tainers™ (Stuewe and Sons, Corvallis, OR) and Spencer-Lemaire Rootrainers™ (Spencer-Lemaire Industries Ltd., Edmonton, AB), respectively. The Ray Leach Cone-tainers™ have a soil capacity of 10 in^3 (164 cm^3) and a depth of 8.25 in (21 cm). The Spencer-Lemaire Rootrainers™ (Hillson size) have a soil capacity of 10.5 in^3 (172 cm^3) and a depth of 5 in (12.7 cm). The Cone-tainers™ were filled with peat, vermiculite, and perlite (4:3:1) growing mix, while the Rootrainers™ were filled with Grace Company Forestry mix. All seedlings received Rapid-Grow supplemental fertilizer ($23N:19P_2O_5:17K_2O$) for the first month; thereafter they received Universal fertilizer ($16N:15P_2O_5:16K_2O$) once per week. Seedlings were watered daily using a hand watering can. Seedlings were placed in cold storage for winter prior to outplanting in spring. Container seedlings were not pruned prior to outplanting.

The 1- and 2-year-old bareroot seedlings were produced through standard nursery culture at the George O. White nursery. Bareroot seedlings were root-pruned to 10 in (25 cm) and top pruned to 16 in (41 cm) prior to planting.

Outplanting Site and Measurements

The outplanting site is located at the George O. White nursery (NW º of Sec 24, T 33 N, R 9 W). The planting site was previously used as a nursery bed to raise seedlings. The site was prepared for nursery planting by plowing and disking using a tractor. Shortleaf pine seedlings were outplanted on a spacing of 1 by 1 m (3.3 by 3.3 ft) in April 1986 using a soil auger.

Total height (HT, m), diameter (d.b.h., cm), form (stem straightness) and survival were measured September 1993 after eight growing seasons. Volume was estimated using volume of a cone:

$$\text{Volume } (dm^3) = HT * d.b.h.^2 * 0.02618$$

Form was assessed using a 7-point absolute visual scale (1 = very straight to 7 = crooked).

Study Design and Statistical Analysis

Two tests (521 and 522) were outplanted in replicated experiments. Families were randomized within replications. In test 521, 2-year-old bareroot seedlings from 48 families were outplanted in replications 1 through 5; 2-year-old container seedlings from 32 families were outplanted in replications 6 through 9. In test 522, the 1-year-old bareroot seedlings from five families were outplanted in replications 1 through 5; 1-year-old container seedlings from eight families were outplanted in replications 6 through 10. Each plot was a row of four trees.

To ensure an unbiased comparison of bareroot and container stock, the families used for both stocktypes should be the same. Because of varying families across replicates, and the lack of data for replications 2 through 5, analysis was done on 24 families in only two replications in Test 521. In test 522, analysis was done on five families represented in six replications.

Plot means were used for all analyses. Data for each site was analyzed separately using a t-test to test for significant differences among treatments (container and bareroot stock) for survival, height, stem diameter, volume, and form. Survival data were transformed using the arcsine of the square root of the proportional value, but untransformed means were presented for clarity. Statistical significance was tested at $P = 0.1$.

Results and Discussion

Survival

Survival of the 2-year-old container seedlings (82 percent) was significantly greater than that of 2-year-old bareroot seedlings (54 percent), a 52 percent improvement in survival using container seedlings (table 1). These results are consistent with findings from other research on effects of these two stocktypes on survival of southern pines in the United States (Boyer 1989; Barnett and Brissette 2004). Although Barnett and Brissette (2004) found that container seedlings of shortleaf pine had significantly better survival than bareroot seedlings in a study in the Ouachita Mountains of Arkansas, the improvement in survival in their study was probably not operationally meaningful because survival of the bareroot seedlings was greater than 90 percent at age 10. In longleaf pine, container seedlings had higher survival (76 percent) than bareroot seedlings (51 percent) at 5 years (Boyer 1989). The superior survival of container seedlings could be due to container seedlings experiencing less transplant shock and probably having greater root systems than bareroot seedlings. Also, the severe root pruning in the 2-year bareroot seedlings is likely to have contributed to the poor survival.

Although the 1-year-old container seedlings had better survival than the 1-year-old bareroot seedlings, the difference in survival between the two stocktypes was not statistically significant (table 1). The lack of significant differences in the 1-year-old stocktypes may reflect the small sample size.

The 2-year-old container seedlings had better survival than 2-year-old bareroot seedlings in all families (table 2). This suggests that there was no family by stocktype interaction. However, the 1-year-old container seedlings in two of

Table 1—Effects of stocktype on performance of shortleaf pine seedlings after eight growing seasons on two sites at the George O. White State Forest Nursery.

Test number	Item	Container	Bareroot	Increase[a]	*P* value
				percentage	
521	Survival (%)	82	54	52	<0.001
(2-year-old	Height (m)	6.4	6.3	2	0.669
seedlings)	Stem diameter (cm)	7.6	8.6	–12	0.093
	Volume (dm^3)	10.5	13.7	–23	0.087
	Form (score)	1.8	2.5	–28	0.267
522	Survival (%)	77	68	13	0.384
(1-year-old	Height (m)	5.4	5.6	–4	0.577
seedlings)	Stem diameter (cm)	6.4	6.9	–7	0.239
	Volume (dm^3)	7.4	7.9	–6	0.889
	Form (score)	1.9	1.5	27	0.252

[a] Increase, container versus bareroot

Table 2—Effects of stocktype (C = container; BR = bareroot) on family growth performance of shortleaf pine seedlings after eight growing seasons on two sites at the George O. White State Nursery.

		Survival		Height		Stem diameter		Volume	
Test	Family	C	BR	C	BR	C	BR	C	BR
521 (2-year-old)	614	100	50	5.9	7.1	7.1	9.8	8.2	17.9
	619	75	75	4.0	6.5	5.0	7.3	4.8	10.1
	621	75	75	6.7	6.2	7.7	8.5	10.4	12.9
	8126	75	25	5.8	5.2	6.2	5.5	6.4	4.1
	8235	75	100	6.6	7.0	6.8	9.1	10.0	15.5
	8318	100	75	6.8	6.4	7.5	8.5	10.1	12.2
	8326	100	100	6.0	6.6	7.8	9.5	9.6	15.7
	8329	100	25	7.1	6.1	8.4	6.0	13.7	5.7
	8330	75	50	7.0	6.1	8.5	6.8	13.4	7.6
	8331	100	75	6.0	4.7	6.4	5.3	7.2	6.1
	8333	100	100	5.6	6.0	6.6	8.4	8.1	12.8
	8338	100	50	6.2	6.7	6.9	9.3	8.6	14.9
	8340	75	75	6.6	5.5	8.7	6.8	13.6	9.1
	8343	100	50	4.9	6.7	5.0	11.5	3.8	23.3
	8344	100	50	5.9	6.3	7.4	7.8	8.9	9.8
	8345	75	25	6.6	3.6	8.3	5.0	12.4	2.4
	8349	75	50	6.1	6.6	7.7	7.8	10.1	10.3
	8350	50	50	6.1	5.8	6.3	6.8	6.3	8.1
	8353	100	50	5.8	4.9	6.8	7.0	7.8	9.9
	8357	100	75	6.4	6.6	7.4	8.5	10.1	12.6
	8362	100	100	6.2	6.6	8.3	11	11.4	22.9
	8364	100	75	5.5	4.9	6.0	7.5	8.1	11.1
	8365	100	50	6.2	6.5	7.6	8.5	9.9	12.2
	8372	75	75	6.6	5.7	8.3	7.0	12.6	7.9
522 (1-year-old)	614	92	83	5.2	5.3	6.1	6.3	6.5	6.1
	619	58	83	5.5	5.9	6.7	7.2	9.1	8.5
	621	83	67	5.8	6.1	7	7.7	9.6	9.8
	8126	75	17	5.6	5.2	5.9	6	5.7	5.1
	8281	75	92	5.2	5.1	6.2	6.6	6.7	6.8

the five families had lower survival compared to bareroot seedlings, indicating a stocktype x family interaction.

Growth and Form

Two-year-old container seedlings had significantly lower stem diameter and volume growth performance than 2-year-old bareroot stock, but height growth between the two stocktypes was not significantly different (table 1). All growth traits between the 1-year-old stocktypes were not significantly different. The lower stem diameter and volume growth in the 2-year-old container seedlings may be due to the fact that the container seedlings were smaller in stem diameter than the bareroot seedlings at outplanting. Root pruning is likely to have reduced the difference between container and bareroot seedlings. The bareroot seedlings were severely root pruned, and the roots lost a large amount of their unsuberized, absorbtive root tissue. The lack of significant differences in height between the 2-year-old stocktypes may be due to the fact that the bareroot seedlings were top pruned prior to planting. The 2-year-old bareroot seedlings had one-third to one-half of their top pruned off. The lack of significant differences in the 1-year-old stocktypes may reflect the small sample size and top pruning of the bareroot seedlings. Container seedlings have been reported to have superior growth as compared to bareroot seedlings in shortleaf pine (Barnett and Brissette 2004), and in longleaf pine (Boyer 1989). The differences in these findings and our results may reflect differences in site conditions. Barnett and McGilvray (1993) found that when conditions are more stressful, container stock grew better than bareroot stock.

Growth was better in bareroot seedlings than in container seedlings in some families but not in others. For example, bareroot seedlings of families 614 and 8343 had greater than 50 percent greater volume growth than container seedlings, while container seedlings of families 8329 and 8345 had more than 100 percent greater volume growth than bareroot seedlings.

The stem form in 2-year-old container-grown seedlings was lower than bareroot; the stem form in 1-year container-grown seedlings was higher than bareroot. However, the differences between the stocktypes were not statistically significant (table 1).

Conclusion

The results from this study indicate that container stock had greater survival than bareroot stock, but less growth, when planting 2-year-old seedlings. Performance of container stock was similar to that of bareroot stock when planting 1-year-old seedlings. Future studies with container and bareroot shortleaf pine stock in Missouri should take the following into account: 1) better design of tests (for example, randomizing the stocktypes within blocks); 2) replicate the study over diverse sites; 3) determine the effect of seedling spacing on survival and growth; and 4) outplant at different times to determine if container seedlings extend the planting season.

Acknowledgments

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Red Oak Research and Demonstration Area in Phelps Township, North Bay, Ontario—2004 to 2005

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Keywords: red oak, *Quercus rubra,* wildlife management, shelterwood

Introduction

In July 2004, a large stand of red oak (*Quercus rubra*) was harvested in Phelps Township, North Bay District, North Bay, Ontario using the uniform shelterwood system. Most of the stand was harvested to retain 40 percent crown closure, while a very small portion was harvested to retain 70 percent crown closure. During tree marking, an active Northern Goshawk (*Accipiter gentilis*) nest was identified and the appropriate Area of Concern (AOC) prescription was applied. Within the modified cut portion of the AOC, the group selection silvicultural system was used with two different size group openings: the traditional 0.1 ha (0.25 ac) with a diameter of 36 m (118 ft), and a smaller opening (0.05 ha [0.12 ac]) with a diameter equal to 24 m (79 ft) (stand height). The stand is growing on deep loamy-sands and best described as having a “dry” moisture regime classification. A number of studies initiated by Nipissing Forest Resource Inc., Callender, ON, in cooperation with the Ontario Ministry of Natural Resources, Southern Science and Information Section, Peterborough, ON have been established within this harvested red oak stand: (1) group selection, (2) acorn sowing, (3) planting—spacing and pattern, (4) uniform shelterwood, (5) planting stock size and fertilizer at time of planting, (6) tending treatments, and (7) regeneration ecology.

Overall Assessments and Treatments

Soil pits will be dug near each plot to assess soil type, soil texture, and moisture regime. Hobo® weather stations (Onset Computer, Bourne, MA) were established in group openings, 70 percent shelterwood and 40 percent shelterwood areas, to quantify and monitor the effect of the overstory treatments on air and soil temperature and soil moisture. Fisheye lens photography was done in each group opening before and after harvest. In addition, each plot will be photographed at regular intervals (every 2 to 5 years) to quantify the effect of overstory treatments on crown closure. Photo locations will be established for a future chronosequence of each plot.

Technology Transfer

Signage

A sign will be designed and established at the main intersection for members of the public and other interested individuals.

Field Tours

This site will be used as part of all the regular technology transfer field tours conducted by the Forestry Research partnership—Canadian Ecology Centre (teacher's tours, Lakehead University tours, forestry tours, and so on).

Reports

A one-page summary of the studies, with map showing plot locations, will be provided to the Forestry Research Partnership to be included with field tour guide books. An establishment report will be prepared that provides a more detailed discussion of the objectives and methods for each study on the site and detailed maps of plot locations. Status reports will be prepared at the end of each year with updates on treatments and results. A one-page document will be prepared outlining potential treatments for inclusion into the Forest Management Plan Annual Work Schedule. A photo library will be maintained and available to all partners.

The Studies

Group Selection Study

This research focuses on the effect of the size of opening and location within opening on: 1) survival, growth, and condition of planted red oak seedlings; and 2) stocking, density, and condition of natural regeneration of red oak and other tree species.

Research Questions—What group opening size promotes the highest density and best growth of red oak natural regeneration? Are the density and growth of red oak natural regeneration affected by location within the group opening (north, south, east, or west side)? Are the height and diameter growth of planted red oak affected by location within the group opening (north, south, east, or west side)?

Methods—An active Northern Goshawk nest and its associated Area of Concern (AOC) provided an opportunity to test the group selection system for red oak in this stand. The AOC prescription asks for a 50-m (164-ft) radius no-cut buffer, and an additional 100-m (328-ft) radius modified cut buffer, within which 70 percent crown closure must be maintained. After consultation with Brian Naylor, habitat biologist with the Southern Science and Information Section, we marked out four 36-m (118-ft) diameter group openings and four 24-m (79-ft) diameter group openings during the summer 2004 within the 100-m (328-ft) modified cut buffer. The openings were cut in mid-late September 2004. The cumulative effect of openings was 0.5 ha (0.12 ac) within the 6.28-ha (15.52-ac) modified cut buffer, thus an 8 percent opening of the overstory. Subsequent to the cut, one of the large group openings was chosen for the sowing study and is therefore no longer available for the group selection study.

Approaches Used to Answer Research Questions—What group opening size promotes the highest density and best growth of red oak natural regeneration? In group openings, 2- by 2-m (6.6- by 6.6-ft) stocking plots (STARS plots) were established and will be used to assess the stocking, density, and height of red oak regeneration and other tree species. The plots will also be used to assess the cover and height of competing vegetation.

Are the density and growth of red oak natural regeneration affected by location within the group opening (north, south, east, or west side)? STARS clusters have been randomly allocated in north, south, east, and west directions at different distances from the centre of the opening.

Are the height and diameter growth of planted red oak affected by its position within the group opening (north side, south side, east side, west side)? Red oak seedlings (1+0 Jiffy-pots™) were planted at a spacing of 3 by 3 m (10 by 10 ft) in a north/south grid pattern within three of the large openings (100 seedlings) and all four of the small openings (50 seedlings) in early June 2005. During the summer 2005, they will be pinned, numbered, and mapped. We will assess the survival, height and diameter growth, and condition of all pinned red oak seedlings within the group openings.

Red Oak Sowing Study

Acorn sowing focuses on the effect of: 1) frozen storage on acorn germination and early growth of red oak seedlings; and 2) silvicultural system (group selection versus uniform shelterwood) on survival, early growth, and condition of red oak seedlings originating from acorns.

Research Questions—What effect does frozen storage have on the germination rates of acorns sown in the field? Is there a difference between germination rates and early establishment of acorns sown in a group opening compared to a uniform shelterwood at 40 percent crown closure?

Methods—This project was initiated in October of 2004 to investigate the use of sowing red oak acorns to regenerate red oak. We also wanted to see if acorns collected in one year could be stored and used for regeneration over the next 1 or 2 years to bridge the gap between acorn corps. Fall 2004 was a good seed year for red oak in Phelps Township. Therefore, acorns were collected from mid-September until early October. Fourteen pounds (6.4 kg) of acorns were sent to the Angus Seed Plant to be frozen for storage. Another group of acorns were sown immediately.

We also wanted to investigate the role of overstory crown closure in acorn germination and survival and growth of the resulting red oak regeneration. Crown closure might create different microclimates (soil temperature, soil moisture, and so on) or different deer use (browse).

Acorns were planted in clusters of five acorns, aligned in an "X" fashion (spaced 30 cm [12 in] apart) at a depth of approximately 5 cm (0.8 in). Each cluster was spaced 3 m (10 ft) apart along a line (figure 1). The centre of each cluster was flagged with an assessment pin. Fall 2004 acorns were flagged in pink and spring 2005 acorns were flagged in blue. In fall 2004, acorns were pushed into the ground with a piece of dowling, and in spring 2005, acorns were planted to the same depth using a tree-planting tool called Pottiputki.

Approaches Used to Answer Research Questions—What effect does frozen storage have on the germination rates of acorns sown in the field? Fresh acorns were sown in fall 2004 and acorns stored overwinter in frozen storage

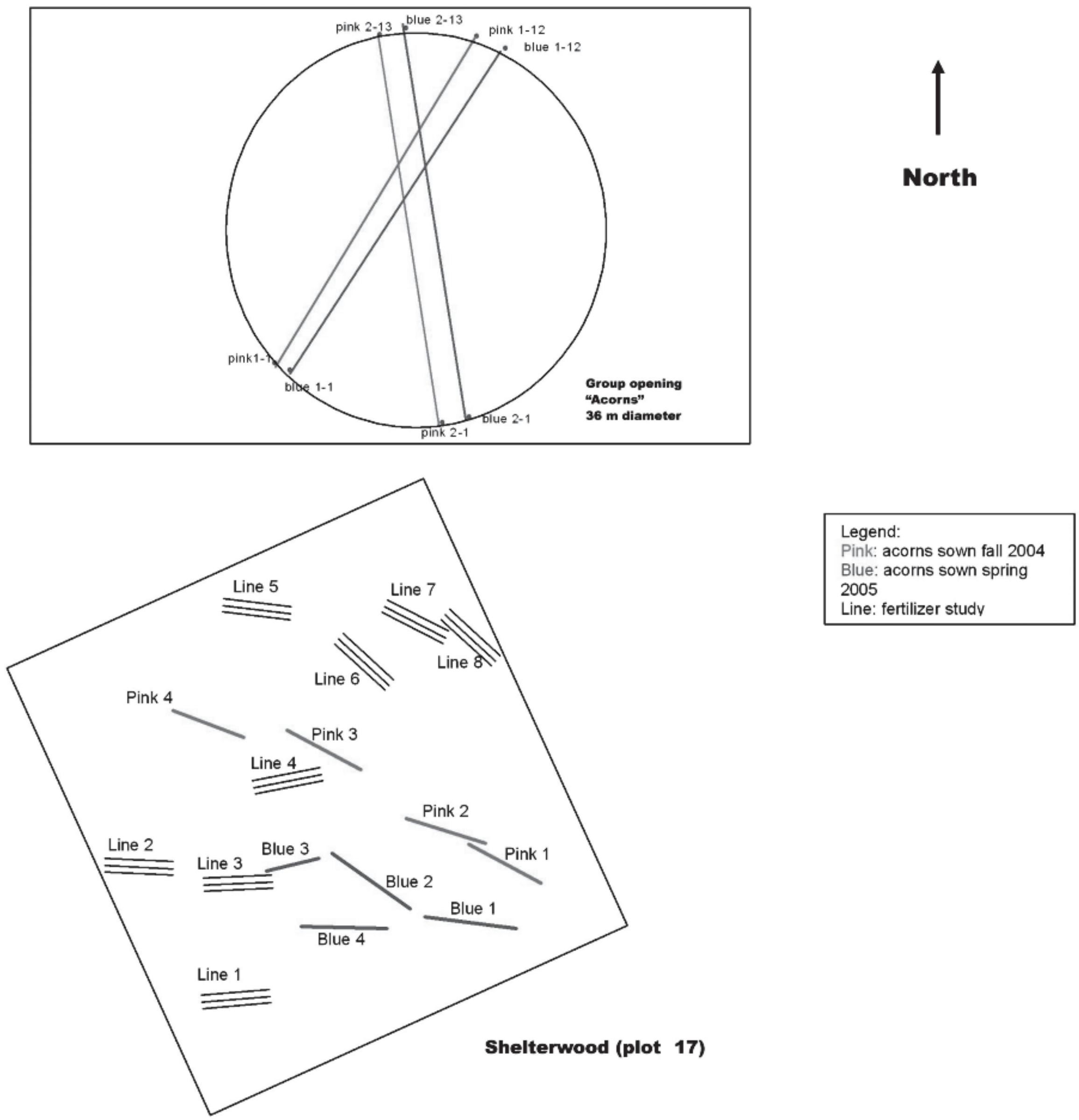

Figure 1—Red oak sowing study. Pink strips were sown in fall 2004 and blue strips were sown in spring 2005 after a winter in frozen storage (–2 °C [28 °F]). Acorns were sown in groups of five spaced 3 m (10 ft) apart along strip. (Note: Acorns sown in fall 2005 are not shown on this map.)

were sown in spring 2005. Sowing plots were examined periodically over summer 2005 to evaluate their germination, growth, and condition. The ability of acorns to germinate after 1 and 2 years of frozen storage will be tested in future sowings in fall 2005 and fall 2006.

Is there a difference between germination rates and early establishment of acorns sown in a group opening compared to a uniform shelterwood at 40 percent crown closure? Fresh and frozen-storage acorns were sown under two different overstory treatments: 36-m (118-ft) group selection opening and a uniform shelterwood treated stand (40 percent crown closure). The group opening (plot 4A, figure 2) contained two 33-m (108-ft) lines (lines 1 and 2) which were established across the group opening in fall 2004, and two more lines (lines 3 and 4) established 2 m (6.6 ft) west of lines 1 and 2 in spring 2005. A total of 12 acorn clusters were established along each transect line.

In the uniform shelterwood site, eight 30-m (98-ft) lines were established across the area that underwent the first cut of a uniform shelterwood treatment; four lines in fall 2004 and four lines in spring 2005. The lines were established along pre-existing skid trails. A cluster of five acorns was established every 3 m (10 ft) along the line (figure 1). The centre of each cluster was flagged with an assessment pin.

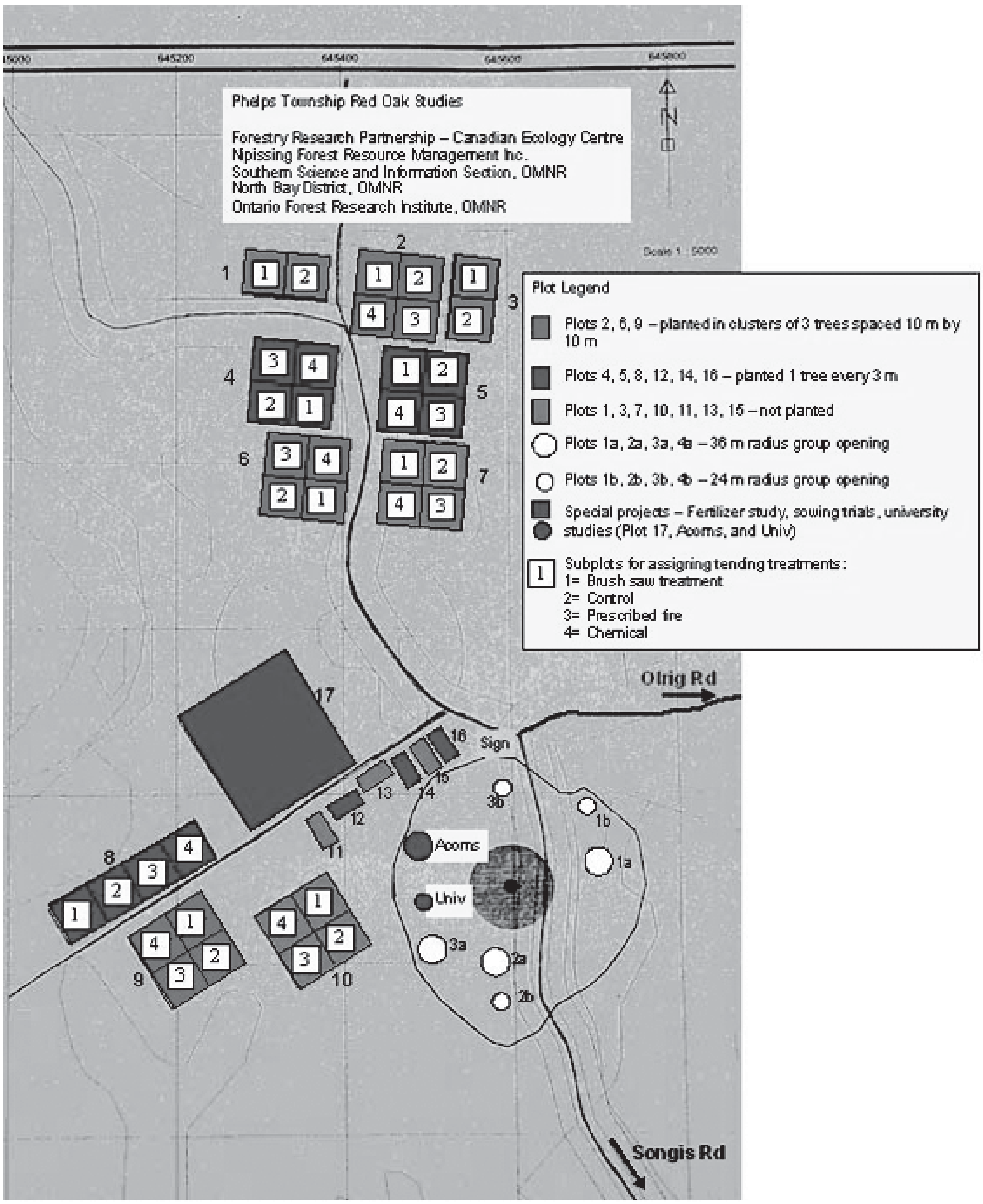

Figure 2—Map of red oak study area in Phelps Township.

Fall 2004 acorns are flagged in pink and spring 2005 acorns are flagged in blue. Each acorn was planted in the soil at a depth of approximately 5 cm (2 in). In fall 2004, acorns were pushed into the ground with a piece of dowling, and in spring 2005, acorns were planted to the same depth using a tree-planting tool called Pottiputki. A total of eleven 5-acorn clusters were established along each transect.

Planting—Spacing and Pattern

This study focuses on the effect of planting spacing and pattern on: 1) survival, early growth, and condition of planted red oak; and 2) stocking and density of red oak regeneration.

Research Questions—How does stocking and density of red oak regeneration differ when trees are planted at 3- by 3-m (10- by 10-ft) spacing compared to three seedlings planted in a cluster at 10- by 10-m (33- by 33-ft) spacing? Is tending facilitated when trees are planted in a cluster at 10 by 10 m (33 by 33 ft) as opposed to the traditional 3- by 3-m (10- by 10-ft) spacing?

Methods—Red oak seedlings in the Nipissing Forest are normally planted at 3- by 3-m (10- by 10-ft) spacing. These red oak seedlings are expensive to produce (1+0 container stock in Jiffy-pots™ cost approximately Canadian $450/1,000) and tending costs can be high if all seedlings (1,100 trees/ha [445 trees/ac]) are released. One alternative is to describe the desired future stand condition and to only establish and tend the number of future trees that are desired, keeping in mind that seedling mortality can be high in the initial 5 years of establishment. On this site, we are aiming for a minimum 30 percent stocking to red oak (to minimize future pest problems), and approximately 100 oak stems/ha (40 stems/ac) at maturity. We estimated that only 30 percent of seedlings that are planted will eventually become crop trees, so we decided to establish three trees at each planting spot (in a triangular formation, each planted seedling roughly 30 cm [12 in] apart) in a 10- by 10-m (33- by 33-ft) grid across the site. So, instead of 1,100 spots, only 100 spots/ha (40 spots/ac) need to be tended and maintained. In both cases, the trees are planted and therefore their distribution is regular across the site. In contrast, natural regeneration tends to be more patchy and irregular.

Approaches Used to Answer Research Questions—How does stocking and density of red oak regeneration differ when trees are planted at 3- by 3-m (10- by 10-ft) spacing compared to three seedlings planted in a cluster at 10- by 10-m (33- by 33-ft) spacing compared to no planting? Nine 1-ha (2.5-ac) plots were established in the shelterwood area (40 percent crown closure): three were planted at the traditional 3- by 3-m (10- by 10-ft) spacing; three were planted using three seedlings in a cluster at a 10- by 10-m (33- by 33-ft); and three were left for natural regeneration. STARS clusters will be established in each 1-ha (2.5-ac) plot and will be used to assess the stocking, density, and height of red oak regeneration and other tree species. The plots will also be used to assess the cover and height of competing vegetation. Finally, 100 seedlings were pinned in each of the planted plots and will be used to calculate survival.

Is tending facilitated when trees are planted in a cluster 10 by 10 m (33- by 33 ft) as opposed to the traditional 3- by 3-m (10- by 10-ft) spacing? Larger plots are likely required in order to successfully answer this question. However, we will use these plots to identify potential problems, constraints, and options that may lead to a larger, more operational-scale proposal.

Uniform Shelterwood

This study will focus on the effect of two intensities of shelterwood cutting (40 and 70 percent crown closure) on: 1) survival, early growth, and condition of planted red oak; 2) percent cover and height of competing vegetation; and 3) stocking, density, and condition of natural red oak regeneration.

Research Questions—Do survival, growth, and condition of planted red oak differ when it is planted under a uniform shelterwood with 70 percent crown closure compared to 40 percent crown closure? Which crown closure promotes the highest density and best growth of red oak natural regeneration?

Methods—Red oak seedlings were planted at the traditional 3- by 3-m (10- by 10-ft) spacing under two different post-cut conditions on 6 June, 2005. These conditions were uniform shelterwood with 40 percent crown closure (within three 1-ha [2.5-ac] plots, flagged blue) and uniform shelterwood with 70 percent crown closure (within three 20- by 40-m [66- by 131-ft] plots, flagged blue).

Approaches Used to Answer Research Questions—Do survival, growth and condition of planted red oak differ when it is planted under a uniform shelterwood with 70 percent crown closure compared to 40 percent crown closure? Planted red oak seedlings were pinned and numbered in each plot and will be monitored and assessed annually.

Which crown closure promotes the highest stocking and density and best growth of red oak natural regeneration? STARS plots (2- by 2-m [6.5- by 6.5-ft] stocking plots) will be established in the centre of each plot within which the density, height, and percent cover of natural red oak regeneration and other tree species will be monitored.

Planting Stock Size and Fertilizer at Time of Planting

In this research, we will study the effect of two concentrations of fertilizer on the survival and early growth of large and small red oak planting stock.

Research Question—What are the effects of two different concentrations of fertilizer on the survival and early growth of large and small red oak planting stock?

Methods—Prior to planting on 27 May, 2005, Andrée Morneault, Megan Smith (Southern Science and Information, Ontario Ministry of Natural Resources), Ian Kovacs (Nipissing Forest Resource Management Inc.), and Don Willis (Jiffy Products (NB) Ltd. and Preforma) visited Webb's Nursery in Bonfield, ON to examine the red oak nursery stock. Upon examining the seedlings, we asked the nusery to sort them by size: large and small. Only large seedlings were planted into the research areas and the leftover large and the small seedlings were planted into the operational planting areas.

During our visit to Webb's Nursery, we were concerned about the vigour and potential survival of the small seedlings. Therefore, we decided to compare large versus small seedling stock to see if the larger stock has an advantage (relating to survival and growth) over the smaller stock. Don Willis provided us with a tacking agent and fertilizer to further compare the survival and growth of red oak seedlings that were given a fertilizer upon planting as opposed to no fertilizer.

The tacking agent used was called CAST (calcium activated seed tacker) Powder, which is an effervescent formulation of a natural biopolymer that forms a firm gel upon contract with calcium ions. This agent was mixed with the fertilizer in order to hold, or "tack," the fertilizer onto the red oak Jiffy-pots™ containers. The fertilizer was a 20N:8P_2O_5:20K_2O Plantex® High Nitrate Forestry Seedling Special. Two fertilizer rates were tested: 1) light fertilizer rate at 4 mg N/seedling or 20 mg total fertilizer/seedling; and 2) heavy fertilizer rate at 10.5 mg N/seedling or 52.5 mg total fertilizer/seedling.

Approaches Used to Answer Research Questions—Each treatment was applied to 25 seedlings and replicated four times. The treatments were as follows: 1) large seedlings with no fertilizer, light fertilizer, or heavy fertilizer; and 2) small seedlings with no fertilizer, light fertilizer, or heavy fertilizer.

Seedlings were planted on 6 June, 2005. Immediately before planting they were dipped in their respective fertilizer concentrations. Seedlings were dipped so that the entire Jiffy-pot™ was covered in the solution. Seedlings were planted in lines along skid trails (3 lines side by side) in the uniform shelterwood area which was harvested to 50 percent crown closure. Initial measurements, including height, diameter, crown width, and overall health, were taken on 8 and 9 June, 2005. Subsequent growth and survival measurements will be performed each fall, beginning in 2005.

Tending Treatments

The tending treatments will look at the effect of: 1) tending technique (mechanical, chemical, prescribed fire, or untreated control) on the control of competing vegetation and growth response of red oak; and 2) overstory crown closure on the number of treatments required to maintain red oak seedlings in a codominant position with vegetation within a 1 m (3.3 ft) radius around their crowns.

Research Question—Which of four tending treatments provides the best control of competing vegetation and the best growth response of planted and natural red oak regeneration?

Methods—Tending is essential to the establishment of red oak regeneration on this site because of the aggressive and vigorous growth of many species after harvesting. Several species are in the "seedling bank" and respond to the increased light and disturbance created by the harvesting treatments, including red maple (*Acer rubrum*), sugar maple (*A. saccharum*), striped maple (*A. pensylvanicum*), and beaked hazel (*Corylus cornuta*). Species that have seeds stored in the "seed bank" are also stimulated to germinate and grow, for example, field bindweed (*Convolvulus arvensis*), pin cherry (*Prunus pensylvanica*), grasses and sedges, and raspberry (*Rubus* spp.). Other species invade the site through root suckers in response to the parent tree being cut during the harvest (trembling and largetooth aspen [*Populus tremloides* and *P. grandidentata*]). Finally, almost all tree species produce basal sprouts after cutting during the harvest and produce localized, but abundant, competition around their stumps, including red maple, white birch (*Betula populifolia*), and ironwood (*Ostrya virginiana*).

So tending is essential, but when and how should it be done? First, we established a threshold level of competing vegetation that we considered to be "threatening" to red oak regeneration, where "threatening" implies reduced growth or survival. We know the following from previous studies:

- Lateral competition is necessary for good form (small branching).
- Some vegetation on the site is necessary to reduce browsing pressure on red oak regeneration.
- Red oak seedlings need about 2 to 5 percent of full sunlight to meet the energy demands of existing tissue. Light levels below that can be fatal.
- Red oak seedlings require 20 percent of full sunlight to produce positive shoot growth.
- Red oak seedlings show increased height and diameter growth up to 50 to 70 percent of full sunlight.
- Residual trees intercept light, and light levels in the understory are related to crown closure. However, the exact relationship between crown closure and understory light levels is not yet known (we will be measuring this, but have not yet obtained the data). Our working assumption and rule of thumb, based on values reported in the literature, is that the percentage of full sunlight is inversely proportional to crown closure. Therefore, 50 percent crown closure results in 50 percent full sunlight, 40 percent crown closure results in 60 percent full sunlight, and so on.
- In a shelterwood situation, we need to control competing vegetation before it begins to overtop the oak if we wish to maintain 50 to 70 percent full sunlight required to maximize the growth and vigour of red oak regeneration.

Based on this threshold, each plot will be treated as needed.

Approaches Used to Answer Research Questions—Which of four tending treatments provides the best control of competing vegetation and the best growth response of planted and natural red oak regeneration? We will test four tending treatments replicated three times:

1) Mechanical brushing is the most common treatment currently used in central Ontario. Using a brush saw, the operator will clean a 1-m (3.3-ft) radius around the crop tree. The potential outcome will be: a) no control of herbaceous

vegetation; b) rapid sprouting of woody vegetation; or c) retreatment required within 1 to 2 years.

2) Chemical tending with a backpack sprayer will be utilized. Using a pipe or shield, the operator will protect the oak seedling while spraying glyphosate using a backpack sprayer within a 1-m (3.3-ft) radius around the crop tree. The potential outcome will be: a) control of woody and herbaceous vegetation; b) possible injury to red oak; or c) retreatment required within 3 to 5 years.

3) Prescribed burning with two consecutive burns will be done. Fire management staff will burn the plots under appropriate conditions to create a moderate intensity fire that will kill the above ground portion of all vegetation. This vegetation recovers with sprouting of woody vegetation and germination of seeds in the seedbank. The second fire in 1 or 2 years (depending on fuel build-up) kills the regrowth. The potential outcome will be: a) need to wait 3 years before the first fire to allow the red oak regeneration to build up a good root system and to become strong enough to avoid being killed by the fires; b) need good weather and timely and adequate human resources to conduct the fire; or c) retreatment not required.

4) A nontreated control is needed as part of experimental design.

Each treatment plot measures 50 by 50 m (164 by 164 ft). We will compare the treatments by measuring the following:

1) The number of treatments required to obtain red oak seedlings measuring 3 m (10 ft) in height. Each plot will be assessed every year and evaluated according to the threshold. When more than 50 percent of the trees have vegetation taller than 40 cm (16 in) above their height, a treatment will be applied.

2) Survival, growth, and condition of planted and natural red oak. Within each treatment plot, we will measure the growth (height, diameter) and condition of each of 25 pinned red oak seedlings.

Regeneration Ecology

Dr. Jeff Dech from Nipissing University, North Bay, ON has recently been awarded 2 years of funding under the Natural Sciences and Engineering Research Council (NSERC) industrial research grant program to work on red oak. His research will be focused on regeneration ecology of red oak, including coppice dynamics, acorn predation, nutrient dynamics, competition effects, and so on.

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Designing and Implementing a New Nursery Computer Program at George O. White State Nursery, Missouri Department of Conservation

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Abstract: The most recent computer program upgrade for the nursery was completed in 1992. It was time for a change. Technology changes at a rapid pace, and a 12-year-old program could use improvement. The nursery program went through a total overhaul. This paper outlines steps taken to complete this process.

Keywords: computer program, Microsoft® Access, shipping, inventory management, financial management

Computer Program History

We began entering orders at the George O. White State Nursery, Licking, MO in 1984. Orders were entered at the nursery and data transferred to Jefferson City, MO, for processing. From 1984 to 1991, all reporting, forms printing, and revenue collection were completed in Jefferson City.

In October 1992, a new computer program was implemented at the nursery. This was a custom program written in-house by our Information and Technology section, a programming team consisting of three programmers and one designer. This new program was written in COBOL and ran on an IBM AS/400 platform. It enabled the nursery to enter the orders, print and mail the billing cards, print shipping tags, collect revenue, and generate all necessary reports onsite. This system was used until October 2004 when a new computer program was implemented. As the Information and Technology section phased out the use of AS/400 computers in the department, they wanted the nursery system to be a server-based program using Microsoft® Access. They used much of what we were doing on the AS/400 computers and incorporated it into the program we are using now.

Identifying the Needs of the Operation

The first step in creating a new computer program is to identify the needs of your operation. For our operation, the needs included: 1) processing 12,000+ orders annually and maintaining a transaction history of each order; 2) managing inventory, both estimated and actual; 3) managing financial functions; 4) shipping 50,000 packages, using two common carriers and customer pickup; and 5) the hardware necessary to make this happen.

Processing and Transaction History

We process 12,000+ orders annually. We need to be able to look at the order and see what transactions have been completed, including when an order was shipped, paid, cancelled, and so on. One vast improvement in the new system is the ability to leave text notes on the order in the computer. Previously, we attached hand-written notes to each order we changed, which created quite a filing problem. We usually change something on approximately one-fourth of our orders.

Inventory Management

We operate using an estimated and actual inventory, and sell using an estimated field inventory. However, when we are creating shipping tags, we use an inventory based on what we have actually graded. We needed the ability to look at both inventories at the same time, and the computer program needed both inventories to create billing cards and shipping tags.

Financial Functions

Our new system needs to provide the ability to manage the financial functions necessary for our operation. We accept payment by check, money order, credit card, cash, and wire transfer, and the system must maintain a history of financial transactions by date and type for auditing purposes. It needs to provide the reports necessary to transfer funds from our bank to the Office of the State Treasurer in Jefferson City.

Shipping

The new system must be able to handle our shipping needs. We process around 50,000 packages annually, and the computer program uses certain parameters to determine what will be in the package. These parameters include tree size, physical inventory availability, and payment status. Packages are either shipped or picked up by our customers. We use both United Parcel Service (UPS) and the U.S. Postal Service (USPS) for shipping. The system must be able to interface with the Pitney Bowes Shipping system to transfer addressing information. The program determines which carrier will be used based on parameters we have set up in the system (table 1).

We worked with our local post office to work out a better rate for shipping. The computer sorts our tags by bulk mail center (BMC) zones, and we process those packages by zone. The packages are loaded into mailing containers (provided by the post office) and labeled for those zones. The USPS provides transportation for those containers. Once the trees leave the nursery, they are handled very few times, and the loading time for the USPS truck is minimal.

We have contract pricing for our UPS shipping, and they have waived the special handling fee for open packages. We get a contract discount based on volume and use the hundred weight shipping for our larger orders. Loading trucks for UPS shipping can be very time consuming, and once the packages leave here, they are handled many times before they reach their destination.

Hardware

The hardware needs of the operation are very important. We needed high volume printers with the ability to print quickly on a variety of paper types. We previously used an impact printer which could handle any type of form. When we went to the new system, we were provided with two laser printers. They were fast enough, they just don't necessarily like the forms.

Establish a Timeline

When starting this process, a timeline needs to be established. We decided to have the program implemented in the fall of 2004, which seemed reasonable. Although all aspects of the program should have been done before the season started, we made the mistake of allowing certain parts to be unfinished with the promise that they would be ready when needed. This, unfortunately, caused major problems at our busiest time of the year.

Test! Test! and Retest!

When the program is ready to implement, make sure you TEST it again and again. We tested each and every step through the process, including all possible scenarios and for all potential problems. Then we tested with what we considered a large volume of data, using several hundred customer orders. What we eventually discovered was that it should have been with several thousand orders. We found later that Access cannot handle a high volume of transactions happening at the same time.

Identify and Fix Problems

When a problem is found, get it fixed immediately. Make sure you have the problems resolved to your satisfaction, not that of the programmer. DO NOT COMPROMISE. Make sure the program is what you want.

Anticipate Problems

No matter how much you test, there will be problems. When they do happen, make sure that your programming team understands the severity of the problems resolves the issues quickly. We encountered a major problem when we tried to create shipping tags for our first major shipping date. We had tested the shipping program with several hundred orders and it seemed to work fine. However, when

Table 1—Criteria to determine package shipping method.

United States Postal Service	United Parcel Service
1) Rural address (in-State only)	1) Urban address and out-of-State rural address
2) No more than 10 packages to one address	2) Rural address with more than 10 packages

several thousand orders were in the system, the program couldn't handle all the steps necessary to generate shipping tags. It was then decided that Access could not handle the load, and the program was transferred to a SQL-server. This happened during our shipping season! We had two Information Technology (IT) employees here at the nursery for 3 days fixing a problem, after they had already spent two all-night sessions in our headquarters working on the problem.

Happy Ending

There can be a happy ending! With a few adjustments to be made, we have a computer system that is going to be very usable. We are fortunate that we have staff in our agency up to the task of completing a program like this. We were able to write this program in-house and not have to go to a private vendor. When something goes wrong, we know who to contact.

More Information

When completed, this program will be available to any association members at no cost. If any one would like more information about the new program, please feel free to contact the nursery. I can send you a print-out of the screens we use and answer any questions you have about the program.

Beyond the Asian Longhorned Beetle and Emerald Ash Borer

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Abstract: The Asian longhorned beetle (*Anoplophora glabripennis*) and emerald ash borer (*Agrilus planipennis*) are exotic forest insects that have had severe impacts on host tree species where they have become established in North America in recent years. Several other exotic forest arthropods have also appeared recently in North America, but have gained less notoriety. Although their potential impacts are less, the full extent of their impacts remains unknown. Some examples of these other exotic arthropod species are the granulate ambrosia beetle (*Xylosandrus crassiusculus*), banded elm bark beetle (*Scolytus schevyrewi*), European wood wasp (*Sirex noctilio)*, and a predatory itch mite (*Pyemotes herfsi*).

Keywords: invasive species, *Xylosandrus crassiusculus,* Asian ambrosia beetle, *Scolytus schevyrewi*, *Sirex noctilio*, *Pyemotes herfsi*, bark beetle, wood wasp, wood borers, itch mite

Introduction

Threats from exotic species of forest arthropods have been increasing in recent years. The gypsy moth (*Lymantria dispar*) has long been a component of northeastern U.S. forests and continues to expand its range into Midwestern States. More recently, the Asian longhorned beetle (*Anoplophora glabripennis*) and the emerald ash borer (*Agrilus planipennis*) have had devastating impacts on susceptible host trees where these insects have become established in North America.

The Asian longhorned beetle is a large wood-boring beetle that attacks and kills maples (*Acer* spp.), horsechestnut (*Aesculus* spp.), willows (*Salix* spp.), elms (*Ulmus* spp.), and several other hardwood species. Established populations have been discovered in New York (1996), Illinois (1998), New Jersey (2002), and Ontario (2003) (CFIA 2005; UV ERL 2005; USDA APHIS PPQ 2005a). Eradication efforts have been undertaken for all identified populations. Results of these efforts have been particularly promising in Chicago, IL, where portions of the Asian longhorned beetle quarantine area were deregulated in April 2005.

The emerald ash borer, a wood-boring beetle native to Asia, was detected in 2002 in southeastern Michigan and southern Ontario (Cappaert and others 2005). This insect appears capable of killing all ash (*Fraxinus* spp.) trees it encounters in eastern North America. Several million ash trees have died in six counties in southeastern Michigan. Additional emerald ash borer populations have been detected across the lower peninsula of Michigan and in scattered locations in northwest Ohio and northeast Indiana. A huge multi-agency effort is underway to detect the beetle's distribution and attempt to limit its spread to new areas.

In addition to these well-known species, several other exotic forest pests have been detected in the northeastern U.S. in recent years. They have not achieved the notoriety of the above insects, and most are not likely to reach that level. But the full extent of their potential impacts is unknown. Like the Asian longhorned beetle and the emerald ash borer, several of these insects tunnel under tree bark and into wood and are thought to have entered the U.S. by hitchhiking in solid wood packing materials. Some of these new species have the potential for serious impacts on forest resources.

Granulate Ambrosia Beetle

The granulate ambrosia beetle (*Xylosandrus crassiusculus*), also known as the Asian ambrosia beetle, was first detected in South Carolina in 1974 and spread rapidly throughout the southeastern U.S. (Solomon 1995; Hopkins and Robbins 2005). This wood-boring beetle is now frequently observed in some Midwestern States. It is native to Africa, southern Asia, Indonesia, Australia, and Pacific islands, and attacks a wide variety of broadleaf trees and shrubs.

The black stem borer (*X. germanus*), a closely related ambrosia beetle, was first detected in 1932 in Long Island, NY (Solomon 1995). A native of eastern Asia and central Europe, this beetle is now distributed throughout the eastern U.S. It also attacks a wide array of broadleaf hosts, but will attack some conifers.

These beetles attack by tunneling into the sapwood and constructing branched galleries. An interesting characteristic of attacks by both of these beetles is the presence of "frass toothpicks" or cylindrical strands of excrement and wood particles protruding from the bark. These strands are not present with all attacks, but can be a clear indicator of the presence of one of these beetle species.

Like other ambrosia beetles, the granulate ambrosia beetle and the black stem borer do not feed on the wood of their host tree, but feed on an ambrosia fungus that they introduce into their galleries. Pathogenic fungi (*Fusarium* spp.) may also be introduced or enter beetle galleries and infect the host plant. Unlike other ambrosia beetles, both of these species are rather aggressive and will attack healthy as well as stressed trees. Damage to hosts can be severe and sometimes fatal. The granulate ambrosia beetle was frequently reported damaging and sometimes killing young ornamental and fruit trees across central Arkansas in spring 2005.

The granulate ambrosia beetle is known to attack at least 13 broadleaf species in North America, with some preference shown for sweetgum (*Liquidambar styraciflua*) (Solomon 1995; Atkinson and others 2005). In May 2005, this insect was identified as infesting black walnut (*Juglans nigra*) trees in a southwest Missouri plantation (R. Lawrence, personal observation). This may be one of the first reports of this insect attacking walnut. During 2002 to 2005, frass toothpicks were observed in Missouri on American elm (*Ulmus americana*), sugar maple (*Acer saccharum*), red maple (*Acer rubrum*), Japanese maple (*Acer palmatum*), yellow poplar (*Liriodendron tulipifera*), northern red oak (*Quercus rubra*), goldenrain tree (*Koelreuteria paniculata*), and Chinese chestnut (*Castanea mollissima*) (reports received by the Missouri Department of Conservation). Identities of the specific ambrosia beetles involved were not determined in these cases. In another case, granulate ambrosia beetles were observed attacking a recently carved white pine totem pole in western Missouri in 2002.

Reducing stress on recently planted or nursery trees is important in reducing attacks by the granulate ambrosia beetle. This insect has multiple generations per year. Heavily attacked branches or whole trees should be removed and destroyed to prevent infestations of nearby trees.

Banded Elm Bark Beetle

The banded elm bark beetle (*Scolytus schevyrewi*), a native of central and eastern Asia, was first detected in the U.S. in 2003, attacking and apparently killing elms in Colorado and Utah. The beetle has since been found in over 20 states across the country from California to New Jersey (NAPIS 2004; Negrón and others 2005). In Asia, it attacks elms, weeping willow (*Salix babylonica*), Russian-olive (*Elaeagnus angustifolia*), peashrub (*Caragana* spp.), various *Prunus* species, apple (*Malus* spp.), almond (*Prunus amygdalus*), and others. Thus far, it has been observed attacking only four species of elms in the U.S. (*Ulmus americana*, *U. pumila*, *U. thomasii*, and *U. procera*).

The full impacts of this introduced species are unknown. It is apparently capable of directly attacking and killing mature, drought-stressed elms (Witcosky 2004; Negrón and others 2005), although it is not clear if this beetle can also attack and kill healthy trees. Attacks on fruit trees (*Prunus* spp.) have not yet been reported in the U.S. Nursery and orchard workers should be alert for possible attacks by this new beetle species. The adult banded elm bark beetle is about 3 to 4 mm long and has a dark brown transverse band across a lighter brown upper surface.

The banded elm bark beetle is closely related to the smaller European elm bark beetle (*S. multistriatus*) that vectors Dutch elm disease (DED). Researchers have isolated DED spores from some banded elm bark beetles, although it has not yet been demonstrated that they can act as vectors of the disease (Negrón and others 2005). Many questions remain about whether the banded elm bark beetle might be a more efficient DED vector than the smaller European bark beetle, and how competitive interactions between the two beetle species might affect elm mortality.

It is interesting to note that this beetle already had a transcontinental distribution at the time of its detection in the U.S. The beetle apparently has been present in the U.S. for at least 10 years (Negrón and others 2005), and perhaps several more. Detection of the beetle may have been delayed because its impacts were masked by the continuing loss of elms across the landscape that has been ascribed to DED. It is unknown how much, if any, of this mortality was caused by DED vectored by the banded elm bark beetle, or how much elm mortality was perhaps caused by the beetle directly without the presence of DED. Researchers are continuing to study the biology, ecology, and impacts of the banded elm bark beetle (Negrón and others 2005).

European Wood Wasp

An established population of the European wood wasp (*Sirex noctilio*) was detected near Oswego, NY, in 2005 (Eggert and Dunkle 2005). In its native range in Europe, Asia, and North Africa, this wood-boring insect is considered a secondary pest of pines (*Pinus* spp.). But where this insect has become established in other areas (Australia, New Zealand, South America, and South Africa), it is a serious pest in plantations of exotic pines, particularly North American pine species (Haugen and Hoebeke 2005).

There are several species of wood wasps (or horntails) native to North America that attack conifers, however most of these species primarily attack dead or dying trees (USDA FS 1985). The European wood wasp is a much more aggressive pest of North American pine species. Relatively healthy but stressed pines can be heavily attacked. The female wood wasp drills into a stressed tree with her ovipositor and inserts a symbiotic fungus, toxic mucus, and eggs into the wood. The fungus and mucus act together to cause the death of the tree, resulting in a suitable environment for development of wood wasp larvae (Haugen and Hoebeke 2005). Surveys are being conducted to determine the extent of the wood wasp infestation in New York (USDA APHIS PPQ 2005b). An effective biological control agent is available for use in managing European wood wasp populations. A parasitic nematode (*Deladenus siricidicola*) is capable of infecting wood wasp larvae and sterilizing female adults (Haugen and Hoebeke 2005).

Pyemotes Itch Mites

Not all introduced arthropods that become established on U.S. trees are plant pests. Numerous reports of unseen biting creatures were received by various agencies in Kansas, Nebraska, Missouri, and Texas in late summer and fall 2004. People were complaining of welt-like bites particularly on upper portions of the body, which differed from chigger bites, were associated with outdoor activity, and were commonly associated with raking oak leaves. The culprit was eventually determined to be an itch mite (*Pyemotes herfsi*), an exotic species of a predatory mite that preys on moth larvae in its native range in Europe and has often been reported to bite humans (Peter 2004; Keith and others 2005).

In the U.S., *P. herfsi* preys on midge larvae within oak leaf galls, especially the marginal fold gall on pin oaks. This predatory mite has multiple generations per year and is capable of rapidly building large populations when conditions are favorable (Keith and others 2005). When mature gall larvae drop from oak leaves in late summer, the mites begin dispersing in "mite showers" from trees. The incidence of bites is high for people involved in outdoor activities during these "showers" in late summer and later in fall when raking leaves. This introduced species obviously has an annoying impact on human activities around oaks. But beyond that are the unknown ecological impacts that this species may have on gall insects, other predatory mites, and the relationships of these arthropods with other organisms.

Monitoring and Management Implications

It is obvious from the widespread distribution of some exotic forest insect species recently discovered in North America that these insects were introduced several years ago. In some cases, large numbers of trees have been killed before the new invader has been detected. Increased monitoring and increased awareness of this problem are vitally important for conserving the health of our forests.

Detection monitoring efforts have increased in recent years. For example, the USDA Animal and Plant Health Inspection Service, USDA Forest Service, and various State partners are implementing "early detection and rapid response" programs (USDA FS 2004; USDA APHIS PPQ 2005c). A major part of these efforts thus far has involved the use of trapping surveys to detect exotic wood borers and bark beetles. The banded elm bark beetle and European wood wasp infestations in the U.S. were first detected through these surveys (Negrón and others 2005; USDA APHIS PPQ 2005b).

Along with detection monitoring is the need for education efforts. Raising awareness among forestry professionals and the general public about specific exotic pest threats can greatly enhance early detection. Arborists, nursery workers, foresters, and others who work daily with trees may often be the first persons to detect newly introduced pests. Increasing public awareness of key pathways of introduction of exotic pests (for example, long-distance movement of firewood) and how to reduce risk of introductions to new areas is also very important.

Although it is impossible to manage forests to completely defend against unknown exotic pest threats that suddenly appear, reinforcement of some forest management principles can greatly help. Increasing tree species diversity can potentially reduce the impacts of new pests. Although some exotic pests, such as gypsy moths (*Lymantria dispar*), are generalists in their feeding habits, host species diversity can still be beneficial. Oak defoliation and mortality due to gypsy moths are lower in stands with greater species diversity. In the case of specialist pests such as the emerald ash borer or Dutch elm disease, maintaining species diversity is important to provide a residual forest in the event that the specialists eliminate much of a single tree species. Some Chicago neighborhoods affected by the Asian longhorned beetle have been unfortunate examples of the risk of planting monocultures (Korab 2000). Elms lining the streets of the neighborhoods were killed by Dutch elm disease many years ago. Rows of Norway maples (*Acer platanoides*) planted to replace the elms have now been decimated by the Asian longhorned beetle.

Another important principle is the obvious one of improving and maintaining forest health. Trees that are vigorous, growing on appropriate sites, and not stressed by biotic or abiotic conditions are much more capable of defending themselves against pest attacks. For example, management of the oak decline complex in Missouri often involves harvesting the more drought-susceptible red oak species and increasing the more drought-tolerant pine component on drier sites, where a larger pine component was historically present many decades ago. By improving forest health in terms of oak decline, managers simultaneously will be taking steps that will help reduce the forests' susceptibility to the gypsy moth and other pests that will eventually arrive in Missouri.

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Phomopsis and Sudden Oak Death: A Tale of Two Nursery Nuisances

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Keywords: nursery diseases, Phomopsis blight, *Phomopsis juniperovora*, sudden oak death, nursery surveys, *Phytophthora ramorum*

Introduction

Tree nurseries, by their very nature, provide key components of the disease triangle (pathogen, host, and environment) simply by the widespread planting of susceptible host(s) grown under optimal conditions. Pathogens can severely impact the quality and quantity of seedling stock, making pest management a high priority in successful nursery practice. Careful inspections for symptoms and signs of fungal agents can improve the precision of cultural, chemical, and biological management strategies, as well as alert growers to newly emerging pests of concern. The purpose of this presentation is to highlight two such nursery nuisances and to discuss implications of their introduction, establishment, and management.

Phomopsis

Phomopsis juniperovora Hahn has an annual impact in nurseries that grow eastern redcedar (*Juniperus virginiana*) and Rocky Mountain juniper (*J. scopulorum*) across much of the northeastern U.S. In Missouri, this problem has been steadily increasing at the George O. White State Forest Nursery over the last several years. Part of the problem is believed to be the lack of overall resistance in seed sources and unequal coverage of preventive fungicidal treatments. Because susceptible foliage is present throughout the growing season in seedling beds, systemic fungicides containing the active ingredient thiophanate-methyl must be applied regularly during the growing season. Control of *Phomopsis* blight can be enhanced when chemical application is applied at 7- to 10-day intervals in conjunction with infected seedling removal during this same time period. Better design in delivery systems, particularly in the area of nozzle efficiency, may hold the key to improving treatment for this disease.

Sudden Oak Death (SOD)

The devastating consequences of global movement of pests and plants have been very severe in North America. Dutch elm disease (caused by *Ceratocystis ulmi*), chestnut blight (caused by *Cryphonectria parasitica*), white pine blister rust (caused by *Cronartium ribicola*), butternut canker (caused by *Sirococcus clavigignenti-juglandacearum*), and gypsy moth (*Lymantria dispar*) are but a few grim reminders of what can happen to tree populations without co-evolved resistance. Mountains and oceans that once prevented introduction of unwanted pests are now easily bridged in ever increasing global markets. Though introduction of exotic pests has increased over the years, climatic, topographical, and other barriers may still prevent their establishment. Nurseries will need innovative techniques to detect and prevent the spread of infected plant materials. If new pests become established, eradication will become a costly and time-consuming venture.

One new arrival impacting growers in California and the Pacific Northwest is the fungus *Phytophthora ramorum* Werres, the cause of sudden oak death (SOD), which was first reported in 1995 in central coastal California. Since then, tens of thousands of tanoaks (*Lithocarpus densiflorus*), coast live oaks (*Quercus agrifolia*), and California black oaks (*Q. kelloggii*) have been killed by the fungus, *P. ramorum*. On these hosts, the fungus causes a lethal bleeding canker on the main stem. Laboratory testing on northern red (*Q. rubra*) and pin oak (*Q. palustris*) indicate that these native Missouri trees are highly susceptible to this disease. Infected trees may survive for one to several years. However, once crown dieback begins, leaves turn from green to pale yellow to brown within a few weeks. Black or reddish ooze often bleeds from the cankers, staining the surface of the bark and the lichens that grow on it. Canker rots, slime flux, leaf scorch, root diseases, freeze damage, and herbicide injury, all normal ailments on eastern oaks, may cause symptoms similar to those caused by *P. ramorum*. Missouri's oak resource has been determined to be at moderate risk according to a model developed by the USDA Forest Service based on host availability and climate.

Issue

In March 2004, the USDA Animal and Plant Health Inspection Service (APHIS) reported that two nurseries in California had tested positive for *P. ramorum*. Stock from Monrovia Nursery, Azusa, Los Angeles County and Specialty Plants, Inc., San Marcos, San Diego County were subsequently shipped to many locations throughout the northeastern U.S. In addition, a nursery in the State of Washington, where *P. ramorum* was also discovered, was still nationally distributing plants as recently as February 2005. Because this fungus has a broad host range, plants of greatest nursery concern included camellias (*Camellia* spp.), rhododendron (*Rhododendron* spp.), and viburnum (*Viburnum* spp.). At this time, however, only camellias have been reported to have been shipped nationwide. Given that widely traded ornamentals can carry the pathogen, and that important Missouri oaks are susceptible, there is a significant risk of introduction into eastern forests. Presently, the Missouri Department of Agriculture and APHIS are involved in tracing the origin and destination of potentially infected stock in order to target detection surveys and eradication measures. The USDA Forest Service has established ongoing survey plots in Missouri and surrounding States to monitor for possible spread into native oak forests. The number of States instituting their own regulations to prevent the movement of SOD continues to increase. State regulations are in addition to the Federal quarantine that has been in place since the pathogen's discovery in California rhododendron nurseries in 2001.

Recommendation

Early detection will be important for successful eradication. As confirmation is pending in most States, the best recommendation is to inform the public where to address their calls concerning bleeding and oozing symptoms found on oaks. Because other maladies involving bleeding occur normally on oaks throughout the year, distinction can only be made by collecting a sample and sending it to a laboratory for a tentative identification. Both Missouri Department of Agriculture and the Missouri Department of Conservation diagnostic clinics continue processing samples by cross-checking and, if isolated, forward possible positives to labs in Ohio, Minnesota, and Mississippi for confirmation using polymerase chain reaction (PCR) protocols. Nurseries themselves within infected regions have begun taking steps to change the way in which they grow planting stock. Planting blocks of susceptible host between blocks of nonsusceptible hosts can prevent the movement of the pathogen within the operation. In addition, chemical studies are showing some efficacy. Copper compounds may be used for preventive coating of trunks; phosphorous acid and metalaxyl may be used for curative treatments. Further studies are also underway to determine potential negative effects of these treatments, as well as optimize delivery rates of active ingredients, ideal times, and methods for successful application.

Using X-Ray Image Analysis to Assess the Viability of Northern Red Oak Acorns: Implications for Seed Handlers

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Abstract: This paper discusses the potential to use X-ray image analysis as a rapid and nondestructive test of viability of northern red oak (*Quercus rubra L.*) acorns and the methodology to do so. Acorns are sensitive to desiccation and lose viability as moisture content (MC) decreases, so we examined X-ray images for cotyledon damage in dried acorns to predict seed viability and early seedling growth. When compared to greenhouse growth measurements, the X-ray image analysis proved to be related to seed germination and early seedling growth, even more so than MC. These results suggest that X-ray image analysis may provide a more accurate test for acorn viability than other popular tests. This paper describes how to bring this proposed seed test into practice with the hope of improving nursery efficiency and quality of oak seedlings.

Keywords: acorn, cotyledon, desiccation, *Quercus rubra*, recalcitrant, red oak, X-ray

Introduction

Hardwood plantings are becoming increasingly popular for timber production, conservation, and wildlife benefits (Gardiner and others 2002; Jacobs and others 2004; Ross-Davis and others 2005). In fact, demand for hardwood seedlings often exceeds supply (Michler and Woeste 1999; Gardiner and others 2002). This trend puts pressure on nursery suppliers to increase efficiency in production of hardwood seedlings. Obtaining and maintaining seedlots of high viability is a critical first step to ensure and improve nursery production. Unfortunately, scientific knowledge of hardwood seeds is far behind that of coniferous and agricultural seeds.

The seeds of oaks (*Quercus* spp.) are particularly difficult to store and manage. Hence, they have been termed "recalcitrant" seeds, meaning that they cannot withstand moisture loss without loss of viability (Roberts 1973). Recalcitrant seeds are metabolically active and sensitive to desiccation because, unlike orthodox seeds, they do not undergo maturation drying (Farrant and others 1988). Species with seeds of this classification are in the vast minority, but include the following temperate genera: chestnuts (*Castanea* spp., Pritchard and Manger 1990), buckeyes (*Aesculus* spp.), some maples (*Acer* spp.), and oaks (Bonner 1990). The oak genus is further broken down into two subgenera: the white oaks (*Leucobalanus*), which do not experience any dormancy and germinate in fall, and the red or black oaks (*Erythrobalanus*), which do undergo fall dormancy and do not germinate until the spring.

Methods of seed collection and storage are very important in maintaining high viability of recalcitrant seeds. Seed moisture content (MC) can influence and indicate seed maturity, longevity in storage, and necessity of pretreatments (Bonner 1981). MC is especially critical for recalcitrant seeds, though MC is not the only factor affecting the viability of recalcitrant seeds. Furthermore, recalcitrant seeds must be handled and stored properly between collection and sowing.

Testing seeds for MC and viability is important for efficient nursery production. Currently, several tests are available to evaluate seed quality, including germination rate, seedling growth, accelerated aging, leachate conductivity, tetrazolium staining, and excised embryo (Bonner 1998; Karrfalt 2004). Unfortunately, many of these tests are destructive to the seeds, not entirely accurate, and time consuming to perform. Investigating new techniques to evaluate seed viability may improve the accuracy and efficiency of such testing for oak acorns.

This paper explores the use of X-ray image analysis as a potential test for acorn MC and viability. X-raying seeds to assess insect damage, maturity, and viability is not new to agriculture or forestry. In forestry practices, X-ray analysis has been used to determine maturity and germination capacity of orthodox conifer seeds (Sahlen and others 1995; Shen and Odén 1999). However, the situation is more complicated with recalcitrant seeds, where degrees of desiccation damage must also be assessed. In the 1970s, investigations were undertaken to use X-ray images to determine viability of agricultural and tree seeds (Belcher 1973, 1977; Duffield 1973). Pertaining to recalcitrant seeds, Belcher (1973) determined whether the northern red oak acorns were developed or undeveloped by viewing X-ray images of acorns lying on their side that were either full or empty. Today, X-raying and processing equipment are more advanced, which increases opportunities and ease of using X-ray machines.

Because acorns are large and susceptible to desiccation, an X-ray image analysis may be useful as a rapid and nondestructive test of whole acorns to predict seed viability and seedling performance. Specifically, the degree of separation seen between the cotyledon and pericarp (CP) and between the two cotyledons (CC) may be used to indicate MC and desiccation damage of acorns. This paper describes the background, methodology, and possible application of X-ray image analysis of northern red oak acorns as per Goodman and others (2005).

X-Raying Procedure

To examine desiccation damage and potential viability of acorns, the acorns should be analyzed individually by the following procedure. To obtain a clear view of the cotyledons in the X-ray image, acorns should be arranged vertically (cup scar down) in the X-ray machine. An indented Styrofoam carton works well to keep the acorns in an upright position (figure 1), although any nondense material of uniform thickness should work. Acorns are large enough that magnification is not necessary in the X-ray images; the container of acorns can be placed directly on top of the photographic paper on the bottom of the X-ray machine (figure 2). X-ray images of acorns should show clear contrasts between fully hydrated cotyledons (white) and empty space (black), so a balance must be found between exposure time and intensity. For northern red oak acorns in a Faxitron X-ray machine (MX-20, Faxitron X-ray Corporation, Wheeling, IL, USA), 190 seconds and 28 kilovolt potential (kVp) were found to yield the best images (Goodman and others 2005). Optimal settings are dependent upon the size of the acorn and X-ray machine being used. The photographic paper can be processed, viewed, and labeled immediately (figure 3).

X-Ray Image Analysis

In the X-ray images, the cotyledons of healthy, nondesiccated acorns appear as a solid or nearly solid white

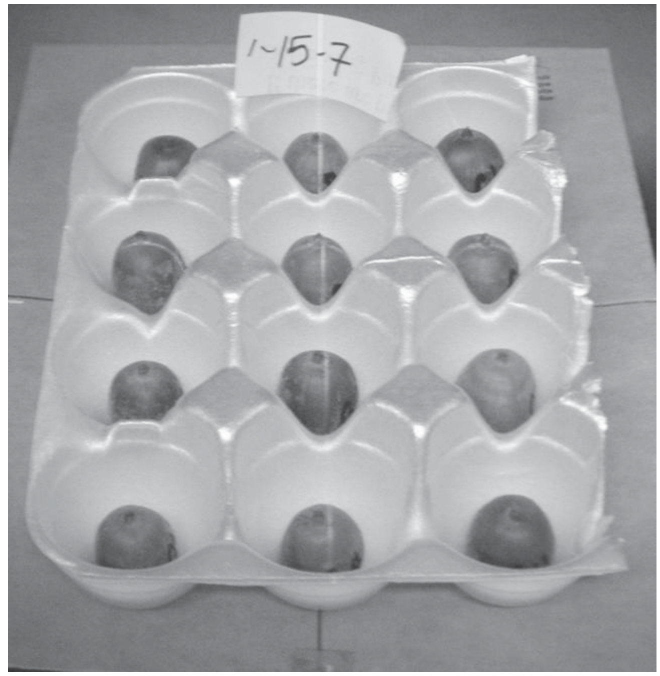

Figure 1—A sample of acorns, arranged vertically in an indented carton, ready to be X-rayed.

Figure 2—Indented carton on top of photographic paper on bottom of X-ray machine.

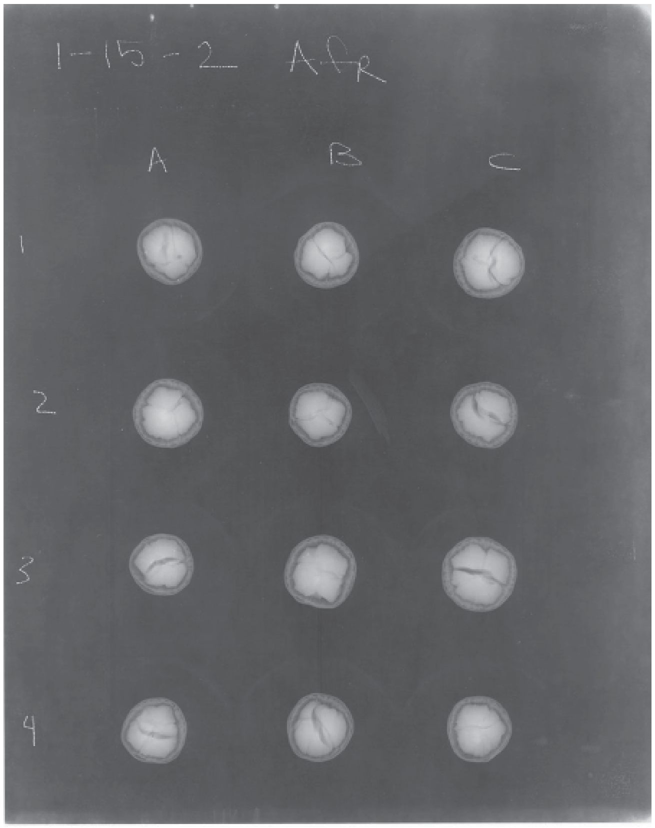

Figure 3—An example of a developed and labeled X-ray image.

image filling the interior of the pericarp. However, lines of separation between the two cotyledons or between the cotyledon and pericarp indicate that the cotyledons have desiccated and shriveled.

X-ray images can be qualitatively scored to assess the desiccation damage of whole acorns by the following technique proposed by Goodman and others (2005). The CC separation and CP separation should be scored individually, that is, 1, 2, or 3 as no, moderate, or severe separation, respectively (figure 4). Quantitative guidelines, (width of separation)/(total width of acorn inside pericarp) X 100 percent, were as follows: < 1 to 1.5 percent, 1 to 1.5 percent to 6 to 7 percent, and > 6 to 7 percent for 1, 2, and 3, respectively. However, these guidelines could not be used absolutely because the length, maximum and average width, and darkness (completeness) of separation should all be considered when assessing damage. Averaging the two X-ray image scores CC and CP (Average X-ray Score = AXS) was found to show the strongest correlation to acorn moisture content and seedling performance (Goodman and others 2005).

Findings and Discussion

When results for X-ray image scores, MC, seed germination, and seedling growth measurements were analyzed, X-ray images scores showed promise to be useful to predict seed viability and early growth (Goodman and others 2005). Percentages to reach each growth stage and final seedling size decreased as MC decreased and as X-ray scores increased (that is, desiccation damage increased). The opposite trend was seen for the number of days needed to reach each growth stage and X-ray image separation scores (that is, more damage), which both increased as MC decreased. When growth measurements were compared directly to AXS, we found that the AXS was a better predictor of seed viability and early seedling growth than MC.

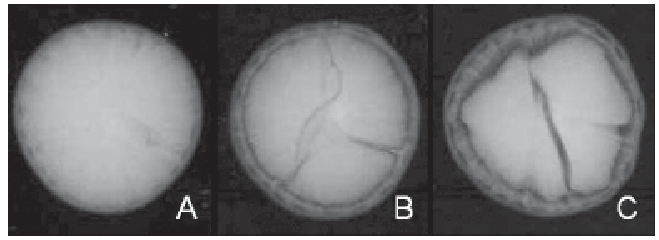

Figure 4—Examples of X-ray images of acorns with three of the nine possible combinations of cotyledon-cotyledon (CC) and cotyledon-pericarp (CP) separation scores. Acorns were qualitatively scored 1, 2, or 3 to designate no, moderate, or severe separation, respectively. Scores corresponding to images, listed as "CC, CP," are as follows: A) 1,1; B) 2,2; and C) 3,3.

This study confirmed that northern red oak acorn viability is very negatively affected by decreasing MC. Hence, acorns should be handled and stored with care in order to avoid desiccation damage. Because viability is highly variable, acorns should be evaluated for MC and viability during the seed handling process to help increase production efficiency. We found that X-ray image analysis of whole acorns predicted seed viability and early seedling performance moderately well, and the relationship was stronger than with MC.

Acorn viability is not solely a function of MC. Many factors have been found to affect recalcitrant seed viability including embryonic MC (Farrant and others 1988; Pritchard 1991), presence of soluble sugars (Sun and others 1994), drying conditions (Farrant and others 1985; Bonner 1990; Pritchard 1991; Liang and Sun 2002), MC before storage, and length of storage (Bonner and Vozzo 1987; Connor and Bonner 1999; Connor and Sowa 2002; Sowa and Connor 2003). While any combination of these factors may affect recalcitrant seed viability, we think X-ray image analysis was successful because it allowed us to view the internal seed morphological conditions that resulted from a probable combination of deleterious effects.

Application

We believe X-ray image analysis may be used as a rapid and nondestructive test of acorn viability and seedling performance. It may be a more accurate test than other tests, for example, MC, cut, or float tests. Because the test yields immediate results, it may be beneficial to X-ray seeds during several stages of the seed-handling process. For example, it could be useful to X-ray a sample of acorns before painstakingly collecting many more acorns from a natural stand or before purchasing a batch of acorns brought to a nursery. Since X-raying is nondestructive, it may be an especially useful test of viability of scarce or valuable lots of acorns.

We hope that the proposed technique will be used in small-scale research projects and nursery operations in the near future. If X-ray image analysis proves to be useful in these situations, it may be beneficial to create a digital image analysis system to quantify the X-ray images and develop an appropriate quantitative formula relating CC and CP separation to performance to improve accuracy and efficiency of this technique. With continued technological advancements, a cost efficient system for X-ray image analysis may eventually be applied to large-scale seed management operations to provide a rapid and nondestructive prediction of acorn viability and seedling performance.

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Exponential Nutrient Loading as a Means to Optimize Bareroot Nursery Fertility of Oak Species

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Abstract: Conventional fertilization in nursery culture of hardwoods may involve supply of equal fertilizer doses at regularly spaced intervals during the growing season, which may create a surplus of available nutrients in the beginning and a deficiency in nutrient availability by the end of the growing season. A method of fertilization termed "exponential nutrient loading" has been successfully used in propagation of several conifer species, but this technique has not been tested in hardwood culture. By supplying fertilizer nutrients in an exponential manner, nutrient supply more closely matches plant nutrient demand, which may improve fertilizer uptake and use efficiency. The amount of fertilizer needed to maximize nutrient reserves and growth before inducing toxicity is termed the "optimum" nutrient loading level. Because optimum levels have not been established for hardwoods, we examined the response of northern red oak (*Quercus rubra*) and white oak (*Q. alba*) to a range of nutrient loading treatments at a bareroot nursery in Indiana. Ammonium nitrate was applied at rates ranging from 0X to 4X the current conventional rate. Seedling morphological and nutritional parameters exhibited responses consistent with the conceptual model for nutrient loading depicting points of deficiency, sufficiency, luxury consumption, and toxicity. Maximum seedling biomass production occurred at 1.0X the current seasonal rate, establishing the sufficiency level. Maximum nitrogen (N) content in seedling tissues peaked at 2.0X the current seasonal rate reflecting the optimum loading rate. Toxicity occurred at 3.0X the current seasonal rate and above, which increased tissue N concentration, but reduced dry mass and N content. This type of analysis may assist nurseries in refining fertilization practices and producing high quality seedlings for outplanting.

Keywords: seedling quality, nutrient loading, exponential fertilization, *Quercus rubra*, *Quercus alba*

Introduction

Success of natural regeneration of oak species (*Quercus* spp.) in the forests of the Central Hardwood Region has been reduced in recent years. This is the result of changes in disturbance patterns, such as fire, that traditionally favored development of oaks. Forest management practices, such as single and group tree selections for harvesting hardwoods, have further reduced the success of oak regeneration because they do not create sufficient canopy openings to allow oak seedlings to compete with shade tolerant species such as maple (*Acer* spp.) and beech (*Fagus grandifolia*) (Larsen and Johnson 1998; Rogers and Johnson 1998; Clatterbuck and others 1999).

Conservation tree plantations are a viable option to maintain a sustainable supply of oak species in the Central Hardwood Region. Many of these plantations are established on abandoned agricultural fields or mine reclamation sites where soil conditions are limiting to tree growth. In Indiana, a recent survey indicated that the overall survival rate for these plantations is 66 percent; only 33 and 53 percent of northern red oak (*Quercus rubra*) and white oak (*Quercus alba*), respectively, were consider free-to-grow at age five (Jacobs and others 2004). This suggests the need for new silvicultural techniques that may improve survival and growth of outplanted seedlings.

Exponential Fertilization

Enhancing potential for field survival and growth of oak seedlings begins in the nursery. Most oaks are produced in bareroot nurseries in the Central Hardwood Region. Traditional nursery culture in these nurseries involves the supply of fertilizer in equal doses at regularly spaced intervals over the growing season. This may create a surplus of available nutrients in the beginning when the seedlings are small and a deficiency by the end of the growing season due to growth dilution (Imo and Timmer 1992). A method of exponential fertilization, termed "nutrient loading," may be used to help match nutrient supply with the growth rate of cultured seedlings (Ingestad 1979; Imo and Timmer 1992; Timmer and Aidelbaum 1996; McAlister and Timmer 1998). Closely synchronizing nutrient supply with seedling demand improves fertilizer uptake and use efficiency. Seedlings are not only able to grow to the maximum morphological standards set by the nursery industry, but may uptake extra nutrients at the luxury consumption level and store these nutrients as reserves in seedling tissues for use once outplanted.

Figure 1 is a proposed conceptual model illustrating the relationship between plant growth, nutrient concentration, and nutrient content with increased fertilization (Timmer 1997; Salifu and Timmer 2003b). It is divided into three sections to demonstrate points of nutrient deficiency, luxury consumption, and toxicity with increased nutrient supply. Seedlings exhibit maximum growth at the sufficiency level. The optimum point is reached when growth and nutrient uptake are both maximized, which occurs during luxury consumption. When fertilized at the optimum level (just prior to toxicity), the seedling is able to store maximum nutrients in its stem and root tissues for later utilization.

Exponential nutrient loading has been successfully used with a variety of conifer species (Timmer 1997; McAlister and Timmer 1998; Salifu and Timmer 2003b). Many studies of exponential fertilization have reported improved outplanting performance of exponentially cultured seedlings that may be associated with the use of stored excess N that is retranslocated to support new growth (Malik and Timmer 1995; Salifu and Timmer 2001, 2003a). Rapid growing exponentially cultured seedlings may better compete with natural vegetation, reducing the need for herbicide application, promoting rapid height growth to free-to-grow status, and possibly helping to minimize deer browse damage.

Given the improved performance of conifer seedlings cultured using exponential fertilization, we suspected that this technique may also be useful for bareroot nursery propagation of oak seedlings. Thus, we established an experiment to 1) compare conventional nursery fertilization practices to: exponential methods; 2) determine the sufficiency level (maximum growth) and the optimal loading level (highest

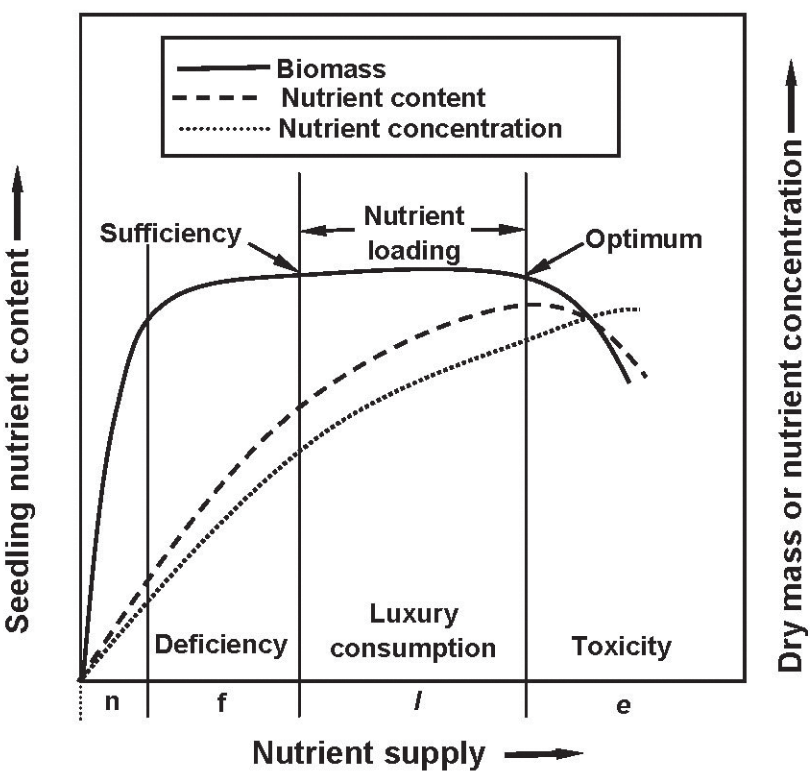

Figure 1—Relationships between nutrient supply with plant growth, tissue nutrient content, and concentration. Fertilizer (*f*) is added to supplement native fertility (*n*) to prevent nutrient deficiency and maximize growth to the sufficiency level. Optimum nutrient loading is achieved by adding fertilizer (*l*) that induces luxury consumption to build up plant nutrient reserves for outplanting. Excess fertilization (*e*) inhibits growth due to toxicity (adapted from Salifu and Timmer 2003b).

level of luxury consumption before toxicity is reached) by fertilizing at eight levels using the exponential method; and 3) analyze elemental N content in structural plant tissues at various stages of growth during the first year.

Study Procedure

This study was conducted at Vallonia State Nursery south of Indianapolis, IN. Soil texture class was sandy loam with 65 percent sand, 23 percent silt, and 12 percent clay. Seeds of northern red and white oak were obtained from local sources and mechanically sown in the fall of 2003 in high densities (9 to 10/ft^2 [97 to 108/m^2]) to obtain about 6 seedlings/ft^2 (65 seedlings/m^2) after germination. Once the seedlings had germinated, plots were thinned to 120 seedlings per plot to allow for more uniform densities. The seedlings were grown as bareroot stock for one season.

Standard nursery practices were followed for all seedlings except for the fertilization treatments. Treatment plots were 4 by 5 ft (1.2 by 1.5 m) to allow a density of 6 seedlings/ft^2 (65 seedlings/m^2). There were four beds with each of the 10 treatments represented to provide 480 seedlings per treatment per species. A buffer of 2 ft (0.6 m) between treatment plots was installed and a randomized complete block design was used for assigning the treatments. An additional bed to either side of the study and 25 ft (7.6 m) in front of the plots and 15 ft (4.6 m) after the plots were left unfertilized as buffers to prevent fertilizer drift from other nursery operations. The study was established as a randomized complete block design, and each species was designated as an independent experiment.

Ammonium nitrate (34N:0P_2O_5:0K_2O) fertilizer in a solid crystal form was broadcast manually on the individual treatment plots. A regime that followed the nursery's current application rate of 206 lb/ac (231 kg/ha) in seven equal applications every 2 weeks (1,444 lb/season [655 kg/season]) was the conventional treatment. A treatment that received no fertilizer (0 lbs) represented a control to examine the effect of the indigenous soil fertility on seedling growth. Eight treatments were based on the modified exponential method of fertilization to match nutrient supply with seedling growth. Seasonal dose rates were 0.5X, 1.0X, 1.5X, 2.0X, 2.5X, 3.0X, 3.5X, and 4.0X the current seasonal rate (see totals in table 1). Table 2 shows how some of these fertilizer treatments (exponential method at the 0.5X, 1.0X, 1.5X, and 2.0X rates) might be applied on a per acre basis at a nursery.

Fertilizer treatment amounts were divided across seven applications and applied bi-weekly, which started shortly after the first full flush of leaves. The application schedule followed procedures described in detail by Salifu and Timmer (2003b) and Timmer and Aidelbaum (1996). A modified version of exponential fertilization was used as per Imo and Timmer (1992).

Once the seedlings emerged and had developed their first flush of leaves (representing the baseline), five seedlings per plot (20 per treatment) were removed from the soil to preserve all the root parts possible and placed in coolers for

Table 1—Bi-weekly fertilization schedule for northern red oak (amounts given are grams of N per plant).

Time Treatment	0 wks 1	2 wks 2	4 wks 3	6 wks 4	8 wks 5	10 wks 6	12 wks 7	Total
Zero	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Conventional	0.120	0.120	0.120	0.120	0.120	0.120	0.120	0.84
0.5 Exp	0.031	0.033	0.039	0.051	0.066	0.100	0.100	0.42
1.0 Exp	0.078	0.065	0.068	0.089	0.124	0.207	0.207	0.84
1.5 Exp	0.138	0.098	0.093	0.121	0.179	0.315	0.315	1.26
2.0 Exp	0.209	0.132	0.115	0.149	0.230	0.423	0.423	1.68
2.5 Exp	0.287	0.165	0.136	0.174	0.279	0.529	0.529	2.10
3.0 Exp	0.369	0.198	0.154	0.197	0.325	0.633	0.633	2.51
3.5 Exp	0.459	0.231	0.172	0.220	0.371	0.738	0.738	2.93
4.0 Exp	0.554	0.264	0.188	0.240	0.416	0.843	0.843	3.35

Table 2—Proposed fertilization schedule to implement exponential fertilization techniques in nursery operations, given as lbs ammonium nitrate (34N:0P_2O_5:0K_2O) per acre (1 lb/ac = 1.12 kg/ha). All exponential seasonal rates are based on conventional season rates, so 0.5X, 1.0X, 1.5X and 2.0X are stated (totals). These rates have been tested in northern red oak and white oak nursery production systems as discussed in this study. The 1.0X rate was the sufficiency amount and the 2.0X rate was the optimum amount.

Time Treatment	0 wks 1	2 wks 2	4 wks 3	6 wks 4	8 wks 5	10 wks 6	12 wks 7	Total
Conventional	206	206	206	206	206	206	206	1,444
0.5 Exp	54	56	67	88	113	172	172	722
1.0 Exp	134	112	118	153	214	357	357	1,444
1.5 Exp	238	169	161	208	307	542	542	2,167
2.0 Exp	359	226	199	256	395	727	727	2,890

further lab analysis. Samples were washed, measured (stem height and root collar diameter) and then pooled into root, shoot, and leaf parts. These were dried for 72 hours at 158 °F (70 °C) and weighed for dry mass determination. Samples were ground in a Wiley mill and mixed to create a uniform powder for chemical analysis. This procedure was repeated at weeks 0, 4, 8, 12, and 16 before application of fertilizer.

The seedlings were mechanically lifted in early December 2004 by cutting at a depth of 10 in (25 cm) for the white oak and 12 in (31 cm) for the red oak to retain as much of the root mass as possible. Harvested seedlings were further processed and stored at 36 °F (2 °C).

Results and Discussion

For each species, seedling growth and nutritional responses to the different fertility rates resembled that of the conceptual model shown in figure 1. For example, seedling growth increased with N rates in the deficiency range (< 1.0X rate), remained fairly stable in the luxury consumption range (1.0X to 2.0X rates), and began to decline at the higher N range (> 2.0X rates), suggesting toxicity. When compared to unfertilized seedlings, fertilization significantly increased plant biomass (figure 2). Similar trends were seen in shoot height growth and root collar diameter. During the growing season, five flushes were observed in the red oaks for all treatments except the control. Color of the leaves between treatments was noticeably different, with the controls exhibiting chlorosis (figure 2). The exponential treatments beyond the 1.0X rate were dark green compared to the conventional treatment. Greater leaf biomass was also observed in seedlings grown in the luxury consumption range. Thus, it could be presumed that the greater leaf biomass and darker leaf color were indicative of the presence of more chlorophyll and greater photosynthetic ability. This could allow the plants to provide increased carbon and N resources for growth sinks once outplanted.

By the end of the growing season (4 months), the 1.0X and 2.0X rates (exponential) had the highest biomass in red oak regardless of tissue part. By contrast, all the exponential fertility rates in white oak, other than that in the toxic range, had higher biomass than the conventional fertilization method. Similar trends were detected for tissue N content.

Figure 2—Experimental plots of red oak showing the contrast between seedlings grown without fertilizer in buffer plots (foreground) and those grown under various conventional or exponential fertilizer schedules.

We expect to formally publish these results in a referred journal in the future.

Conclusions

This study was able to demonstrate the importance of N fertilization in nursery culture of oaks. We also found that that the principles of exponential nutrient loading (examined in detail by many authors for conifer species) appear to also be applicable to oak species. Luxury consumption of N was induced in these two oak species, and seedlings appeared able to store excess N in seedling tissues beyond that needed to maximize morphological growth. Increased growth and N uptake occurred with the exponential treatment even though the total N delivered over the entire growing season did not vary from current conventional practices. Exponential nutrient loading has potential to improve nursery seedling quality of oaks by maximizing morphological development and optimizing nutrient storage reserves in plant tissues. Simultaneously, the process has potential to improve fertilizer use efficiency, thereby decreasing fertilizer costs and leaching losses. Additional studies need to closely examine responses of nutrient loaded hardwood seedlings during outplanting, and examine performance of additional hardwood species under this fertilization technique.

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