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Abstract

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This proceedings is a compilation of 30 papers that were presented at the regional meetings of the Forest and Conservation Nursery Associations in the United States in 2004. The joint meeting of the **Southern Forest Nursery Association** and the **Northeastern Forest and Conservation Nursery Association** occurred July 12 to 15 at the Embassy Suites Hotel in Charleston, South Carolina. The meeting was hosted by the South Carolina Forestry Commission, Taylor Nursery. In addition to technical sessions, tours of the Baucom Containerized Nursery and Mead/Westvaco Nursery were included. The **Western Forest and Conservation Nursery Association** meeting was held at the Red Lion Inn in Medford, Oregon, July 26 to 29. The meeting was hosted by the USDA Forest Service, J Herbert Stone Nursery. Morning technical sessions were followed by field trips to the J Herbert Stone Nursery and to restoration outplantings on the Timbered Rock Fire of 2002 in southern Oregon. Subject matter for both sessions included nursery history, conifer and hardwood nursery culturing, greenhouse management, fertilization, pest management, restoration, and native species propagation.

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

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

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Technical Coordinators

R. Kasten Dumroese, Research Plant Physiologist, USDA Forest Service, Southern Research Station, 1221 South Main Street, Moscow, ID 83843; telephone: 208.883.2324; FAX: 208.883.2318; e-mail: kdumroese@fs.fed.us

Lee E. Riley, Supervisory Operations Forester, USDA Forest Service, Dorena Genetics Resource Center, 34963 Shoreview Road, Cottage Grove, OR 97424; telephone: 541.767.5723; FAX: 541.767.5709; e-mail: leriley@fs.fed.us

Thomas D. Landis, Research Nursery Specialist, USDA Forest Service, Retired, J Herbert Stone Nursery, 2606 Old Stage Road, Central Point, OR 97502-1300; telephone: 541.858.6166; FAX: 541.858.6110; e-mail: nurseries@aol.com

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Contents

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

Joint Meeting of the Southern Forest Nursery Association and the Northeastern Forest and Conservation Nursery Association

Charleston, SC

July 12–15, 2004

Controlled Release Fertilizer Improves Quality of Container Longleaf Pine Seedlings

R. Kasten Dumroese
Jeff Parkhurst
James P. Barnett

R. Kasten Dumroese is Research Plant Physiologist, USDA Forest Service, Southern Research Station, 1221 South Main Street, Moscow, ID 83843; telephone: 208.883.2324; e-mail: kdumroese@fs.fed.us. Jeff Parkhurst, formerly Container Technician, North Carolina Division of Forest Resources, Claridge State Forest Nursery, Goldsboro, NC. James P. Barnett is Chief Silviculturist and Project Leader, USDA Forest Service, Southern Research Station, Alexandria Forestry Center, 2500 Shreveport Highway, Pineville, LA; telephone: 318.473.7214; e-mail: jpbarnett@fs.fed.us

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Abstract: In an operational trial, increasing the amount of nitrogen (N) applied to container longleaf pine seedlings by incorporating controlled release fertilizer (CRF) into the media improved seedling growth and quality. Compared with control seedlings that received 40 mg N, seedlings receiving 66 mg N through CRF supplemented with liquid fertilizer had needles that were 4 in (10 cm) longer as well as 42%, 84%, and 47% greater root collar diameter, shoot biomass, and root biomass, respectively. We use data from this study and other published sources to make general, practical guidelines concerning appropriate levels of fertilization for longleaf pine seedlings in containers.

Keywords: nitrogen, seedling quality, seedling viability, nursery production

Introduction

Longleaf pine (*Pinus palustris*) is an important reforestation species in the South. Longleaf pine's fire tolerance, resistance to bark beetles, better growth on sand ridges, and higher value as sawtimber makes it, for some landowners, a more secure investment than other southern pines (Hainds 2002). Secondary products like pine straw for landscaping and the fact that longleaf stands can be managed in a variety of ways also favor its use (Outcalt 2000). As a result, production of longleaf pine in containers surged during the past decade to meet demand caused by changes in United States farm policy, seed scarcity, longer planting windows afforded by container stock, and better performance of container seedlings over bareroot seedlings on outplanting sites (see Dumroese and Barnett 2004).

The only guidelines available for growing container longleaf pine are the interim guidelines suggested by Barnett and others (2002a,b). Their guidelines encourage seedlings with root collar diameters (measured on the hypocotyl directly below the base of the needles) >3/16 in (4.8 mm) and nonclipped needle length of 8 to 12 in (20 to 31 cm). Root collar diameter is important; South and others (1993) found that seedlings with larger diameters survived better and grew more vigorously after outplanting than seedlings with smaller diameters.

Generally, to obtain root collar diameter, growers must apply sufficient nutrients to stimulate growth (Montville and others 1996). Too much nitrogen (N) can result in lush, excessively long needle growth. Long needles can lodge and cover seedlings, disrupting irrigation and fertilization applications and promoting disease (Barnett and McGilvray 1997, 2000). To prevent lodging, needles can be clipped; with high doses of N, seedlings are often clipped several times. Excessive clipping (trimming needles to less than 15 cm [6 in]) can reduce growth (Barnett and McGilvray 1997, 2000). Usually, clipping is done by hand. Ideally, growers would like techniques to increase root collar diameter while controlling needle growth without clipping, thus avoiding the high labor costs associated with this practice.

The staff at Claridge State Forest Nursery in Goldsboro, North Carolina, asked for assistance in improving the root collar diameter of their longleaf pine seedlings. In reviewing their cultural regime, we noted that seedlings were given fairly low doses of fertilizer early in the growing season, a time when seedlings can begin developing significant root collar diameter. Our objective was to see if addition of a controlled release fertilizer (CRF) to the crop might improve early season growth, result in seedlings with larger root collars by the end of the growing season, and produce acceptable seedlings without resorting to needle clipping.

Methods and Materials

Our operational trial was conducted at the Claridge State Forest Nursery in Goldsboro, North Carolina. Previous to this study, longleaf pine seedlings were grown outdoors on tables in Ropak® Multi-Pot #6-45 containers (Table 1) filled with 2:2:1(v:v:v) peat moss:vermiculite:perlite custom mixed at the nursery, and fertilized via a tractor-pulled spray tank.

For this experiment, we had 2 treatments: (1) seedlings grown in medium with CRF, and (2) seedlings grown in medium without CRF (control). For the CRF treatment, the nursery staff used a mixer to incorporate 4 lbs 18N:6P_2O_5:12K_2O Polyon® controlled release fertilizer (9 month release rate; Pursell Technologies, Inc., Syla-cauga, Alabama) per cubic yard of medium (2.37 kg/m^3). Since each container cavity had a volume of 98 cm^3 (Table 1), the medium in each cavity contained about 42 mg N via the polyurethane-coated prills. For the control treatment (no CRF), 3 lbs dry 10N:10P_2O_5:10K_2O were incorporated per cubic yard (1.78 kg/m^3) to the medium described above—the medium in each cavity contained about 17 mg N.

In early May, randomly selected Ropak® containers were machine filled with the media described above and sown with seeds from the orchard at Bladen Lakes State Forest in North Carolina. Filled containers were transferred to an outdoor growing area. This area had been historically divided into 2 sections, so we installed a block in each section with 3 replications of each treatment per block (we had about 5,000 seedlings per replication).

Liquid fertilizer (Peter's 20N:20P_2O_5:20K_2O; The Scotts Company, Marysville, Ohio) was applied to both treated and control seedlings 8 times during the growing season as per the discretion of the nursery manager to maintain adequate growth of control seedlings. Of these eight applications, five were made at 10 lbs N/ac, one at 15 lbs N/ac, and two at 30 lbs N/ac (11.2, 16.8, and 33.6 kg N/ha, respectively)—based on cavity density of the Ropak® container (Table 1), we estimate that each seedling received about 24 mg N via these 8 applications. Therefore, control seedlings received about 41 mg N (17 from incorporated + 24 from liquid) over the course of the growing season whereas treated seedlings received 66 mg N (42 from CRF + 24 from liquid).

One month after planting (mid-June), and then once every month throughout the growing season (mid-July, mid-August, mid-September), we collected a random sample of 25 seedlings from each replicate for morphological evaluation. Length of the longest needle and root collar diameter were recorded. Shoots and roots were separated, dried at 150 °F (65 °C) until constant weight (about 48 hours), and weighed for biomass. Dried tissues were ground to pass a 0.04 mm mesh, and analyzed for total N and C content with a LECO–600 analyzer (LECO Corp., St. Joseph, Michigan).

For each dependent variable, data were analyzed using analysis of variance procedures in Statistical Analysis Software (SAS 1998). The stepdown bootstrap method was used to adjust p-values for family-wise error (Westfall and Young 1993).

Table 1—Characteristics of Ropak® Multi-Pot #6–45 used at Claridge State Forest Nursery, Goldsboro, North Carolina.

Cavity characteristics	English	Metric
Volume	6 in^3	98 ml
Diameter	1.5 in	3.8 cm
Density	54 per ft^2	581 per m^2

Results and Discussion

Morphology

Seedlings provided an additional 42 mg N via controlled release fertilizer had longer needles, thicker root collars, and more biomass than control seedlings (Figure 1). By mid September, needles on CRF-treated seedlings were about 4 in (10 cm) longer than those of control seedlings. Needle length for control seedlings was, however, within the interim guidelines of Barnett and others (2002a,b) and although needles of the treated seedlings were 1.5 inches longer (3.5 cm) than the guideline, we did not encounter problems with lodging. As with height, root collar diameter of control seedlings met the minimum guideline of 3/16 in (4.8 mm), but root collar diameter of treated seedlings was 42% greater, averaging 1/4 in (6.8 mm). Shoot and root biomass were also increased by controlled release fertilizer, 84% and 47% respectively. For all of these seedling characteristics, the magnitude of the effects of controlled release fertilizer became most apparent 2 to 3 months following sowing. Over the course of the growing season, the relationships between the N content of seedlings and resulting seedling biomass, root collar diameter, and needle length were similar (Figure 2).

Nitrogen

On the last sample date, about 41% (17 mg) of the 41 mg of N applied to the control seedlings resided in the seedlings, whereas about 59% (39 mg) of the 66 mg N applied to the treated seedlings resided within them.

For treated and control seedlings, N concentration in shoots and roots was high 1 month after sowing (Figure 3), and decreased precipitously from values of 3% to 4% to values around 1% after 3 additional months of growth. Nitrogen concentration and content in treated seedlings was significantly higher than the control at the end of the growing season ($P < 0.0001$). Although seedling N concentrations dropped, seedling total N content continued to increase for treated and control seedlings. In the control seedlings late in the growing season, however, the increase in total N content occurred concurrently with a slight decrease in

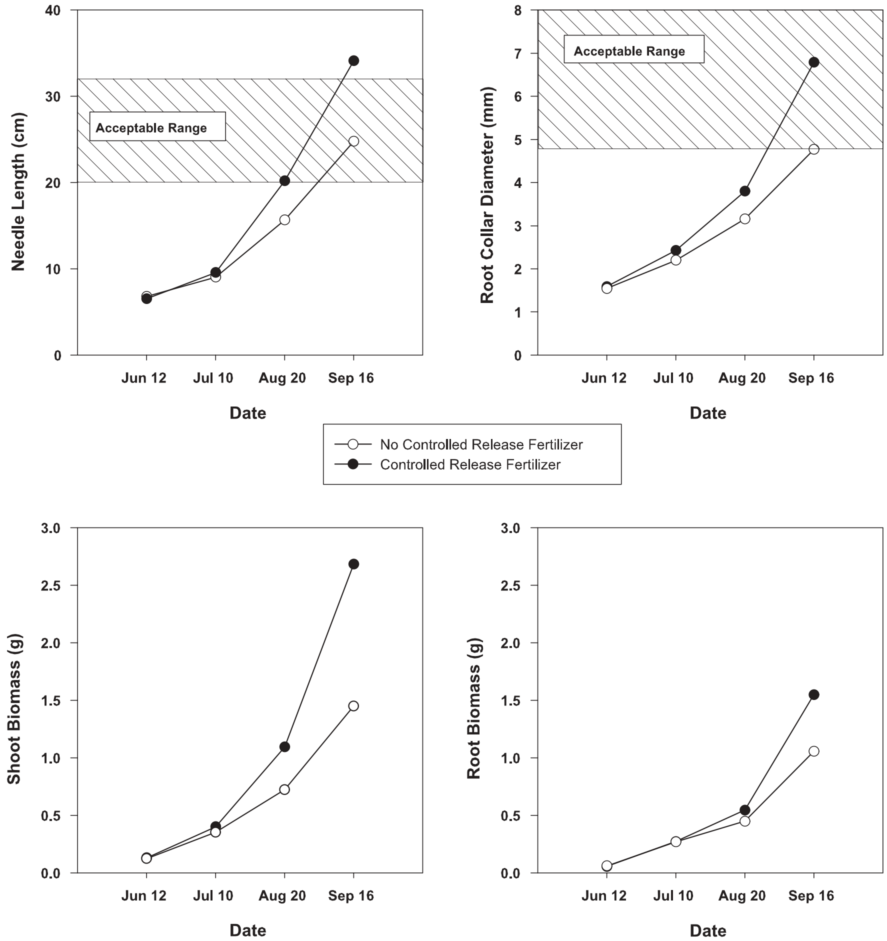

Figure 1—Mean morphological characteristics of control seedlings and seedlings provided an extra 42 mg N via controlled release fertilizer. Seeds were sown in mid May. For needle length and root collar diameter, the acceptable ranges are based on interim guidelines suggested by Barnett and others (2002a,b).

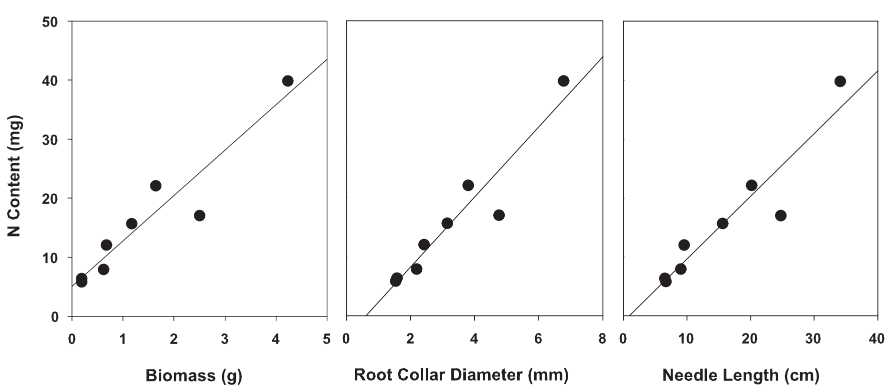

Figure 2—The relationships between longleaf pine seedling N content and biomass, root collar diameter, and needle length were linear and well correlated ($R^2 > 0.9$). This similar relationship makes it unlikely that fertilization can be manipulated to favor one characteristic without favoring the others.

shoot N content, perhaps a reflection of preferential translocation of N by the seedling to roots or variation in seedling samples.

Discussion

We used a polymer-coated controlled release fertilizer, considered to be the most technically advanced because it provides efficient (gradual and consistent) nutrient delivery. The desired nutrients, surrounded by the polymer, are known as prills. Nutrients are released as water diffuses through the polymer coat (Goertz 1993). Diffusion is accelerated by warmer soil temperatures (Kochba and others 1990), and manufacturers generally provide estimates of how long it takes for 90% of the nutrient to be released at an average temperature of 70 °F (21 °C) (Goertz 1993). The product in this study had a 9-month release rate, so, presumably, not all of the N in the prills had been made available to the seedlings. Unfortunately, without tests of the medium, we do not know for sure how much N was released from the prills and made available to seedlings. In addition, different

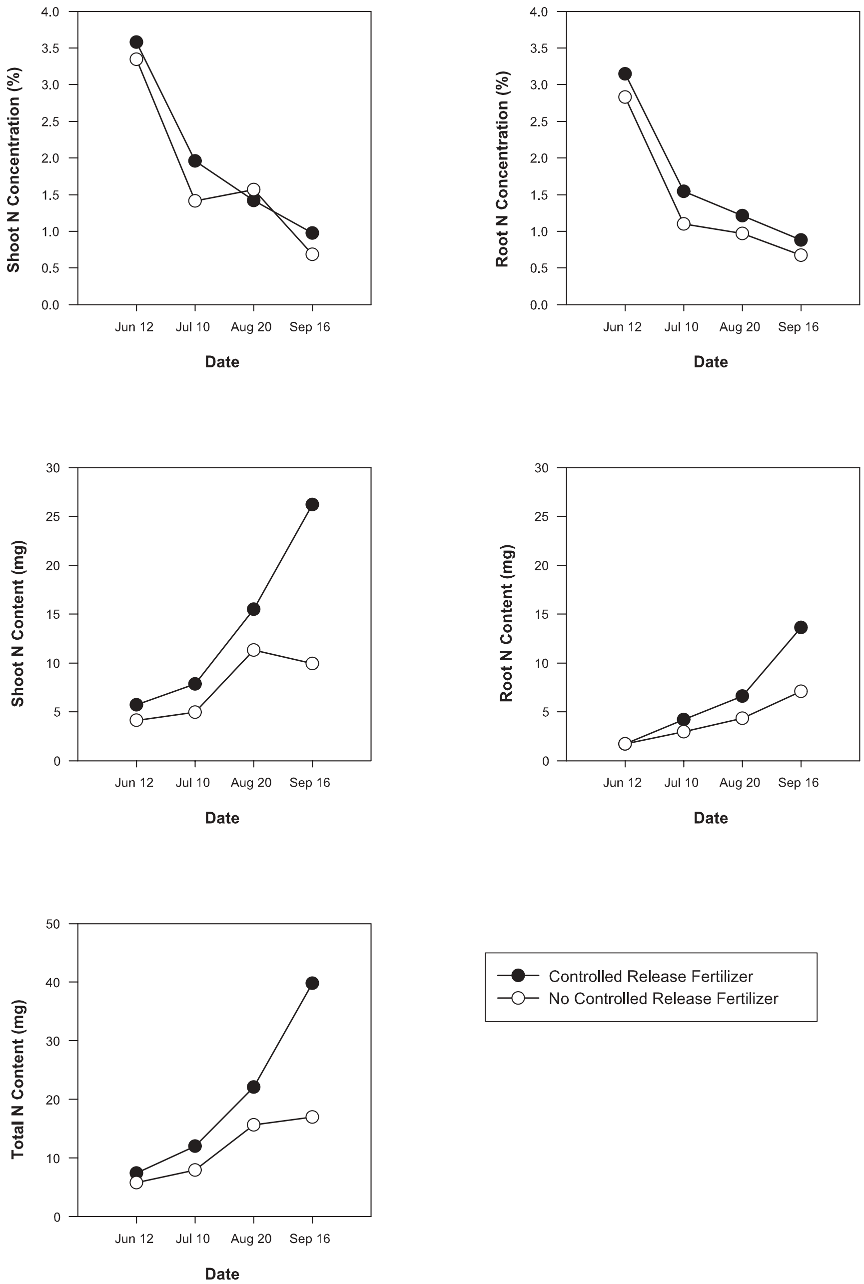

Figure 3—Mean nitrogen concentrations and contents in shoots and roots of controlled release fertilizer. Seeds were sown mid May.

controlled release fertilizers with different polymers release nutrients at varying rates.

The decrease in shoot and root N concentrations throughout the growing season, concurrent with increases in total N content within treated and control seedlings and sustained seedling growth, indicates that N was probably available in the optimum range even when shoot N concentrations were <1%. If so, then this particular seed source was likely in luxury consumption of N for most of the growing season, even when N concentrations were <2%. This value is much lower than the luxury consumption value proposed for most conifers (Dumroese 2003).

Over the course of the growing season, the similar relationships between the N content of seedlings and resulting seedling biomass, root collar diameter, and needle length make it appear unlikely that seedling N fertilization can be manipulated in favor of one of these variables without favoring the others. Therefore, nursery managers are forced into a give-and-take situation between maximizing root collar diameters and minimizing frequency of needle clipping.

Our initial objective was to find a N rate that yielded longleaf seedlings with: (1) root collar diameters within the range proposed by Barnett and others (2002a,b), and (2) needle lengths that did not require clipping. Our results seemed to indicate that the CRF rate used in this study met that objective. Safe and steady nutrient release by the controlled release fertilizer successfully augmented liquid fertilization and the result was seedlings of higher quality. We were curious as to how our rates compared to other growing regimes. Very little information is available concerning fertilization regimes for container longleaf pine, but 2 papers that we found provide similar recommendations. Barnett and McGilvray (1997) suggest applications of 350 ppm N of 15N:16P_2O_5:17K_2O but with this caveat: weekly applications will provide maximum root collar diameter but necessitate clipping, perhaps several clippings, to prevent needle lodging whereas less frequent applications of this rate can reduce or eliminate clipping at the expense of smaller root collar diameters. Starkey (2002) recommends fertigation 3 times per week using a balanced fertilizer as well, either 20N:20P_2O_5:20K_2O or 15N:15P_2O_5:15K_2O. Starkey advocates using 50 ppm N for 2 weeks during the establishment phase, increasing up to 200 ppm N during the exponential phase that lasts about 15 weeks, followed by 25 to 50 ppm N for a 5-week hardening phase.

On the other hand, Pittman (2002; 2004) uses 4 lbs 17N:6P_2O_5:10K_2O Miester® controlled release fertilizer (9-month release rate; Helena Chemical Company, Collierville, Tennessee) per 24 ft^3 of medium (2.67 kg/m^3). Miester uses a synthetic thermoplastic resin as a coating. Ten weeks after sowing, Pittman adds 9N:45P_2O_5:15K_2O at 11 lbs/ac (12.3 kg/ha), making a single application each week for 6 to 8 weeks. About 12 applications from week 10 through early November of 20N:20P_2O_5:20K_2O are made at 11 lbs/ac (12.3 kg/ha) to give the seedlings a healthy green color.

To compare these regimes, we assumed that seedlings were grown in Ropak® Multi-Pot #6–45 (see Table 1), received 0.5 in (15 ml) of fertilizer solution per fertigation, and were fertigated once per week for 20 weeks. On this basis, 101 mg N would be applied per seedling using Barnett and McGilvray (1997), 110 mg N using Starkey (2002), and 44 mg N using Pittman (2002, 2004). Our control seedlings received 41 mg N and our CRF-treated seedlings 66 mg N. Our seedlings receiving 66 mg N were borderline for requiring clipping but achieved acceptable root collar diameter growth.

Based on this preliminary data, we feel that some general fertilizer guidelines can be drafted to accompany the interim seedling quality guidelines. The fertilizer guidelines are still broad (Table 2). The actual fertilizer needed to meet target seedling specifications depends on the intrinsic characteristics of nursery, including variables like seed source and weather, the fertilizer type, and the philosophy and budget of the nursery manager (Dumroese and Wenny 1997; Starkey 2002). If additional costs associated with clipping can be justified by increased value of the crop to customers (through enhanced root collar diameters), then a heavier fertilizer regime may be satisfactory. Barnett and McGilvray (1997) caution, however, that clipping needles to a length less than 6 in (15 cm) can reduce stock quality.

Conclusions

Container longleaf pine seedlings given between 40 and 100 mg N over the course of a growing season, either through liquid fertilization, controlled release fertilizer, or some

Table 2—Fertilizer recommendations for container longleaf pine seedlings grown outdoors in Ropak® Multi-Pot #6–45. The target levels, expressed in mg N per seedling, are provided in common application rates for southern nurseries.

Fertilization method		mg N per seedling			
		< 40	**40 to 70**	**70 to 100**	**> 100**
	Comments on application rate	*Too low*	*Yields satisfactory root collar diameter; no needle clipping*	*Yields enhanced root collar diameter; one or more needle clippings necessary*	*Probably excessive*
Fertigation using ppm	Assumes 1 application per week for 20 weeks; 0.5 in (15 ml) of solution per application		135 to 240 ppm N	240 to 345 ppm N	
or					
Fertigation using lb/ac (kg/ha)	Assumes 54 seedlings per ft^2 (581/m^2); applied as liquid fertilizer in equal increments over 20 weeks		207 to 363 lb N/ac (232 to 407 kg N/ha)	363 to 519 lb N/ac (407 to 582 kg N/ha)	
or					
Incorporation into media before sowing	Assumes 6 in^3 (98 ml) volume cavity in the container		0.7 to 1.2 N/$yard^3$ (0.4 to 0.7 kg/m^3)	1.2 to 1.7 N/$yard^3$ (0.7 to 1.0 kg/m^3)	
or					
Fertigation plus incorporation	A combination of the above		Application rates will depend on proportion of each fertilization method used		

combination of both, should meet the interim seedling quality guidelines. At a rate of 40 to 70 mg N, it appears likely that growers can produce seedlings of acceptable quality without having to clip needles. Higher rates of fertilization will increase root collar diameter but probably necessitate the need for one or more clippings during the season. As suggested by Dumroese (2002), we still need some data showing the optimum nitrogen levels to have in container seedlings to yield optimum outplanting performance.

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Seedling Quality Standards for Bottomland Hardwood Afforestation in the Lower Mississippi River Alluvial Valley: Preliminary Results

Douglass F. Jacobs
Emile S. Gardiner
K. Francis Salifu
Ronald P. Overton
George Hernandez
M. Elizabeth Corbin
Kevyn E. Wightman
Marcus F. Selig

Douglass F. Jacobs is Assistant Professor with the Hardwood Tree Improvement and Regeneration Center (HTIRC), Department of Forestry and Natural Resources, Purdue University, West Lafayette, IN 47907; telephone: 765.494.3608; e-mail: djacobs@purdue.edu. Emile S. Gardiner is Research Forester, Center for Bottomland Hardwoods Research, USDA Forest Service, Southern Research Station, Stoneville, MS 38776; e-mail: egardiner@fs.fed.us. K. Francis Salifu is Post-doctoral Scientist, HTIRC, Purdue University; e-mail: fsalifu@purdue.edu. Ronald P. Overton is USDA Forest Service, Area Regeneration Specialist, HTIRC, Purdue University; e-mail: roverton@fs.fed.us. George Hernandez is Southern Region Nursery Specialist, USDA Forest Service, 1720 Peachtree Road NW, Atlanta, GA 30367; e-mail: ghernandez@fs.fed.us. M. Elizabeth Corbin is former Research Technician, Center for Bottomland Hardwoods Research, USDA Forest Service, Southern Research Station, Stoneville, MS 38776. Kevyn E. Wightman is former Post-doctoral Scientist, HTIRC, Purdue University. Marcus F. Selig is Research Associate, HTIRC, Purdue University; e-mail: mselig@purdue.edu

In: Dumroese, R. K.; Riley, L. E.; Landis, T. D., tech. coords. 2005. National proceedings: Forest and Conservation Nursery Associations—2004; 2004 July 12–15; Charleston, NC; and 2004 July 26–29; Medford, OR. Proc. RMRS-P-35. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Abstract: Afforestation of bottomland hardwood species has increased in the Lower Mississippi River Alluvial Valley (LMRAV) in recent years. Rising demand for hardwood nursery stock and poor performance of some planted seedlings has created concern regarding the quality of seedlings currently available for afforestation in the LMRAV. Furthermore, no definitive guidelines for optimal seedling morphological quality of bottomland hardwoods in the LMRAV have been developed. We measured initial morphology of green ash (*Fraxinus pennsylvanica* Marsh.) and water oak (*Quercus nigra* L.) seedlings from 3 nurseries and examined field response after planting with or without chemical weed control on a LMRAV site in Mississippi. Seedlings from different nurseries varied significantly in initial morphology and field performance during the first growing season. Weed control had a relatively minor influence on seedling survival, but growth was significantly increased when weed control was applied. Seedlings exhibited considerable transplant shock during the first growing season, and this stress was most pronounced in seedlings with larger shoot heights, implying possible shoot-to-root imbalance. Though we currently present only preliminary results from a portion of data collected, our results suggest that morphological quality of hardwood seedlings available for afforestation in the LMRAV varies considerably depending on nursery source, and this variation leads to differences in plantation performance.

Keywords: afforestation, green ash, seedling quality, transplant shock, water oak

Introduction

The Lower Mississippi River Alluvial Valley (LMRAV) comprised the largest extent of bottomland hardwood forest in the United States at the time of European settlement, consisting of about 10 million ha (25 million ac) (Hefner and Brown 1985). This area was largely deforested over the past 60 years, primarily for conversion to agriculture. It is estimated that hardwood forest cover in the LMRAV was reduced to about 2 million ha (5 million ac) by 1978 (Hefner and Brown 1985). In recent years, there has been increased interest in afforesting these sites to retain the important ecological function of these ecosystems (Gardiner and others 2002; Lockhart and others 2003). This interest has been strengthened by the apparent poor suitability of some of these sites for agriculture due to tendency for late spring and early summer flooding (Lockhart and others 2003).

Afforestation activities in the LMRAV are currently peaking (Gardiner and others 2002), largely driven by the availability of governmental cost-share programs (for example, the Conservation Reserve Program and Wetlands Reserve Program), which help to supplement planting costs. Within the past decade, about 77,000 ha (190,000 ac) of former agricultural land were afforested in the LMRAV (King and Keeland 1999). It is expected that another 89,000 to 105,000 ha (220,000 to 260,000 ac) will be afforested by 2005 (Stanturf and others 1998; King and Keeland 1999).

Though planting stock on these sites include seeds, container seedlings, and cuttings (Gardiner and others 2002), it has been estimated that over two-thirds of public land and cost-share plantings in the LMRAV have been established using 1+0 bareroot seedlings (King and Keeland 1999). The large increase in demand for hardwood bareroot seedlings for afforestation in the LMRAV has prompted the establishment of many new forest tree seedling nurseries. Additionally, some ornamental nurseries have adapted to the increased demand for seedlings by expanding their operations to include hardwood planting stock.

This has created potential for concern regarding the quality of seedlings currently available for afforestation in the LMRAV. This concern is further augmented by the poor survival and growth of many hardwood plantations in the region (Lockhart and others 2003). A meeting held in June of 2002 at the USDA Forest Service Bottomland Hardwoods Laboratory in Stoneville, MS, with members representing the National Resources Conservation Service (NRCS), the USDA Forest Service, Purdue University, and State agencies from Arkansas, Louisiana, Mississippi, and Texas suggested that a concerted research effort to better define quality specifications for bottomland hardwood nursery stock is needed.

Early researchers working with bottomland hardwood species suggested that desirable seedlings for field planting should have a shoot height of 76 to 91 cm (30 to 36 in) and a root-collar diameter of about 6 to 10 mm (McKnight and Johnson 1980; Kennedy 1981). However, specifications for morphological quality will probably vary among the vast diversity of hardwood species that are planted in the LMRAV (Gardiner and others 2002). Additionally, performance by morphological grade is likely to deviate according to the extent of site preparation conducted on the site. Many afforestation sites in the LMRAV receive little or no weed control measures, which likely limits their productivity. No definitive guidelines for optimal seedling morphological quality of bottomland hardwoods in the LMRAV have been developed or published (Gardiner and others 2002). Thus, our objectives in this current research are: (1) to examine variation in bottomland hardwood bareroot seedling morphological quality among several regional nurseries and resulting outplanting performance, (2) to document the importance of weed control in initial plantation establishment in the LMRAV, and (3) to identify relationships between initial seedling morphology and outplanting performance.

In this paper, we present first-year field trial results for green ash (*Fraxinus pennsylvanica* Marsh.) and water oak (*Quercus nigra* L.) acquired from 3 nurseries (in Arkansas, Louisiana, or Mississippi) and planted onto an afforestation site with or without weed control in the LMRAV in Mississippi. Following the completion of additional growing seasons, we expect to present more comprehensive reports summarizing all treatment combinations.

Materials and Methods

In February 2003, we obtained 1+0 bareroot seedlings of 5 different species commonly planted in LMRAV afforestation programs: pecan (*Carya illinoensis* (Wangenh.) K. Koch), water oak, cherrybark oak (*Q. pagoda* Raf.), Nuttall oak (*Q. nuttallii* Palmer), and green ash. Seedlings from each species were acquired from each of 3 nurseries: Arkansas Department of Forestry, Louisiana Department of Forestry, and the Mississippi Forestry Commission. Note that nurseries are kept anonymous in our report of the results. Seedlings were transported to the USDA Forest Service Bottomland Hardwoods Laboratory in Stoneville, MS, and placed into a cooler until processed.

Each seedling was individually tagged and measured for shoot height, root-collar diameter, fresh weight, number of first-order lateral roots (FOLR, roots >1 mm at junction with taproot), and root volume (Burdett 1979). Seedlings were then re-packaged and returned to the cooler.

Following measurements, seedlings were sorted for planting at 3 different outplanting sites located in Arkansas, Louisiana, or Mississippi. We currently present results from only the Mississippi site located near Rosedale, MS (330 53' N, 910 00' W), and only for green ash and water oak (with or without weed control). The 2 species were established in separate experiments. Green ash was planted on a Sharkey Soil while water oak was planted on a Commerce Soil. Seedlings were planted in a randomized complete block design with 3 replications of the 6 treatments (3 nurseries x 2 weed control levels). Fifty seedlings were planted within a treatment replication for a total of 900 seedlings of each species on a site. Planting was conducted using shovels in February to March 2003. The weed control treatments consisted of either no control or a pre-emergent application of Goal™ 2XL (oxyfluorfen) applied at 4,677 ml/ha (0.5 gal/ac) in early March 2003. Broadcast applications of Select® 2EC (clethodim) were then applied as needed throughout the growing season at a rate of 585 or 877 ml/ha (0.5 or 0.75 pt/ac) depending on target weed species. Additionally, direct applications of Derringer™ (glufosinate-ammonium) were applied at a rate of 118 ml/L (15 oz/gal) of water as needed throughout the growing season.

In March 2003 (following planting and prior to bud burst), each seedling was measured for field height and root-collar diameter. Seedlings were re-measured in December 2003 and assessed for survival. Analysis of variance (ANOVA) was conducted on all variables using SAS and, where appropriate, significant means were ranked according to Waller-Duncan's multiple range tests at a = 0.05. To directly examine relationships between initial seedling morphology and planting performance, regression analyses were employed and a coefficient of determination (R^2 value) reported when statistically significant ($P < 0.05$).

Results

Nursery Characterization

Significant differences were detected for all initial morphological variables among nurseries (identity kept anonymous) for each species. For green ash (Figures 1 and 2), nursery A had the largest shoot height, root-collar diameter, and fresh mass. Shoot height ranked as 75 > 62 > 45 cm (30 > 24 > 18 in) in respective nurseries A, B, and C. Similarly, diameter ranked as 8 > 7 = 7 mm in the respective nurseries. Nursery C, however, had the highest mean number of FOLR and root volume. Additionally, seedlings from nursery C had approximately 50% the ratio of height to root volume (that is, an indication of shoot-to-root balance) compared to seedlings from nurseries A and B.

For water oak (Figures 3 and 4), seedlings from nursery A again had the greatest shoot height, root-collar diameter, and fresh mass. Nursery C again produced seedlings with the greatest number of FOLR, but seedlings from nursery A had the largest root volume. Seedlings from nursery B had the largest ratio of height-to-root volume.

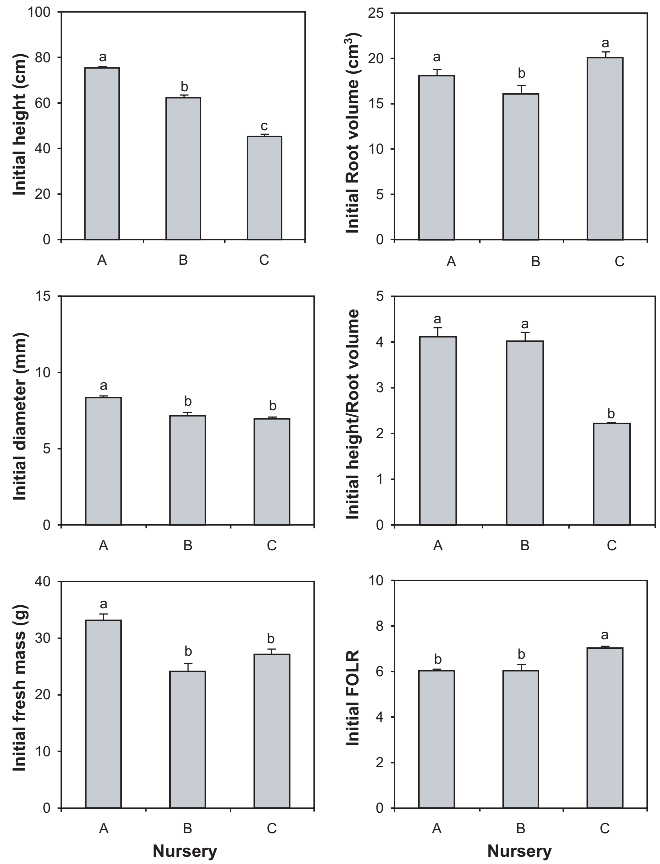

Figure 2—Green ash initial seedling morphological variables according to nursery. Treatments with different letters above the bars are significantly different at a = 0.05.

Green Ash Field Response

Green ash seedlings exhibited significant nursery differences in field response. Seedlings from nurseries B and C had >95% survival, while those from nursery A had about 76% survival (Figure 5). Weed control treatments produced clear visual differences in growth during the growing season (Figure 6). No differences in survival were detected by weed

Figure 1—Typical green ash seedlings exhibiting considerable variation in morphology.

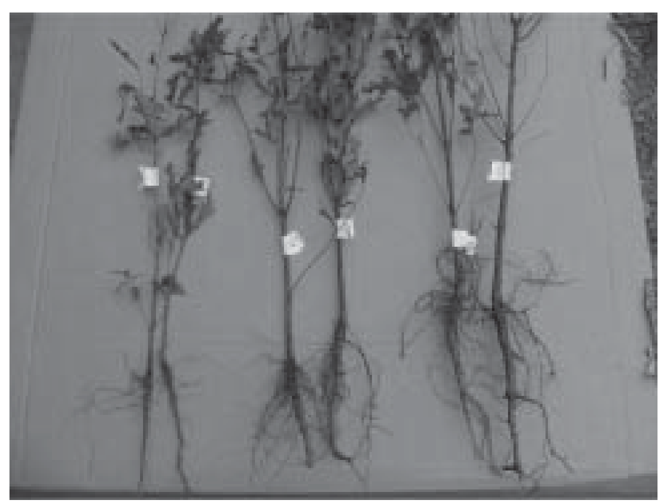

Figure 3—Typical water oak seedlings exhibiting considerable variation in morphology.

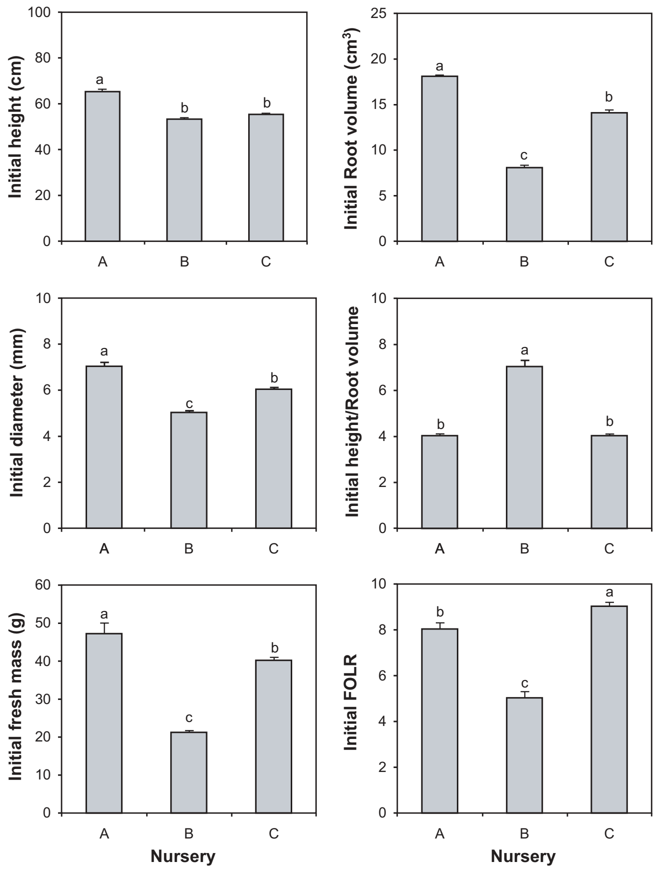

Figure 4—Water oak initial seedling morphological variables according to nursery. Treatments with different letters above the bars are significantly different at a = 0.05.

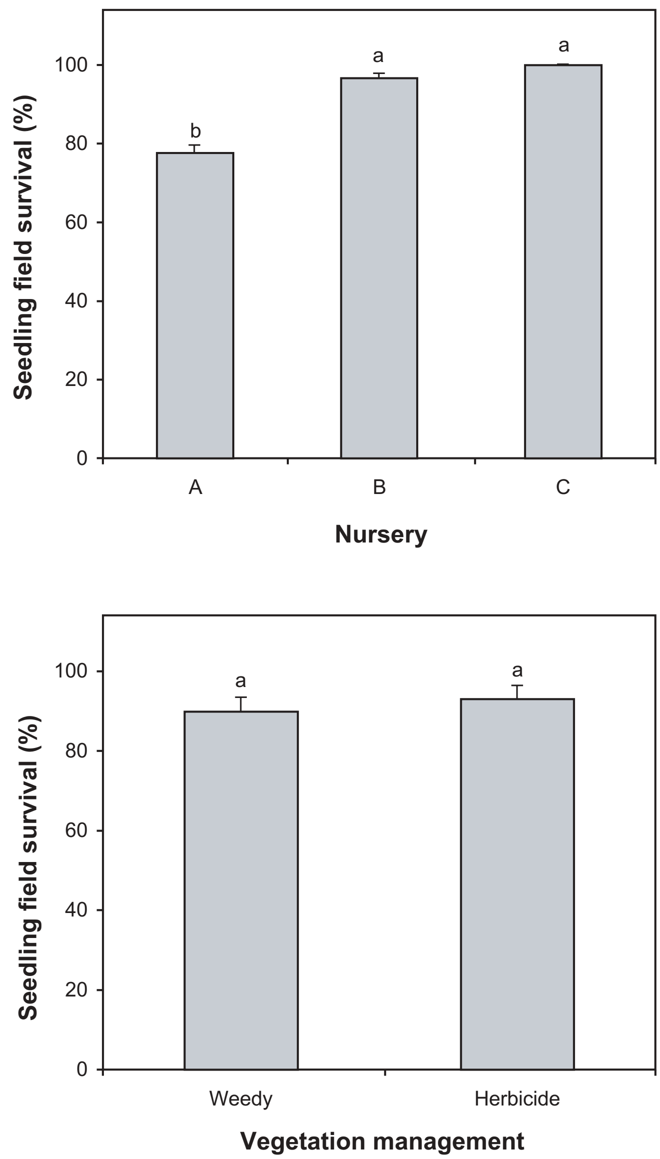

Figure 5—Green ash seedling survival by nursery and weed control treatment. For either the nursery or weed control effects, treatments with different letters above the bars are significantly different at a = 0.05.

control treatment (Figure 5). Differences in seedling growth among nurseries and weed control treatments were very evident (Figure 7). Seedlings from nursery C had the greatest height and diameter growth, while those from nursery A had the lowest. The ranking of this response by nursery was similar whether seedlings received weed control or not. However, seedlings that received weed control grew significantly more than those that did not (Figure 7).

Regression analyses between initial morphological variables measured in the lab and field performance showed a generally negative relationship between initial seedling height or diameter and growth or survival, regardless of weed control treatment (Figure 8). In contrast, initial FOLR or root volume tended to show more stable or positive linear relationships with field performance (Figure 9). With an increase in the ratio of initial height-to-root volume, field performance generally decreased (Figure 10).

Water Oak Field Response

Water oak seedlings showed no differences in survival by nursery, but survival was significantly lower without weed control (Figure 11). Seedlings in all treatments exhibited severe top dieback, resulting in generally negative height growth for all size classes (Figure 12) and preventing further analysis of growth response at present. The relationship between initial lab variables and survival showed a generally positive linear relationship without weed control and a negative linear relationship when weed control was applied (Figure 13).

Discussion

Apparently, there are substantial differences in seedling morphological quality from identical species among nurseries in the LMRAV. These differences in morphology appear to translate to variation in first-year outplanting performance. Green ash seedlings from nursery A, for example, tended to have greater height, diameter, and fresh mass

Figure 6—Green ash seedlings during the first year of plantation growth either with (top photo) or without (bottom photo) chemical weed control.

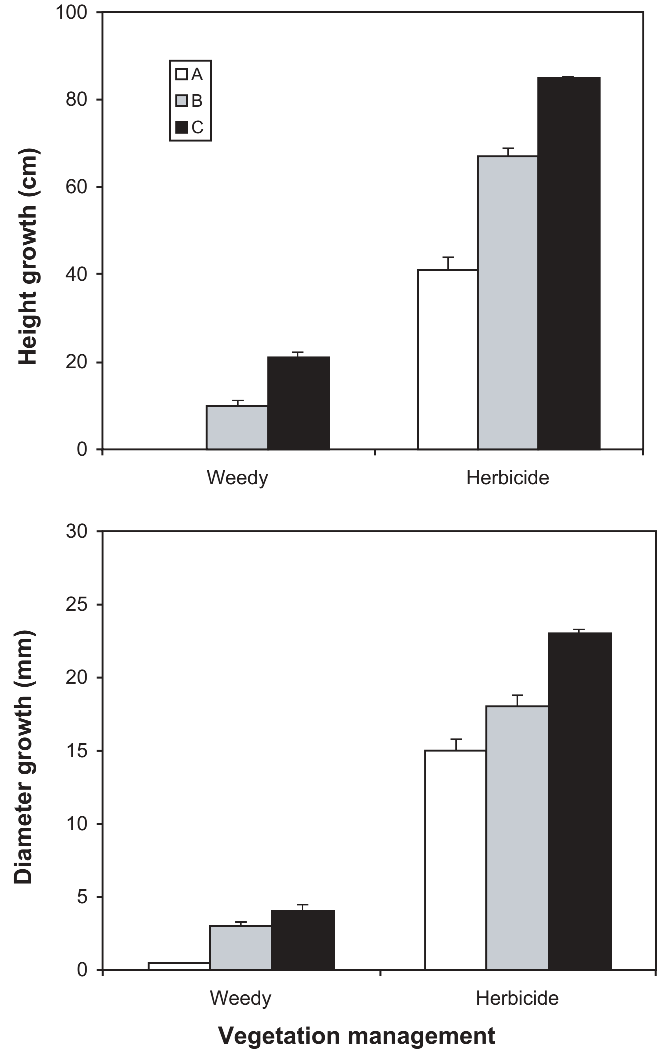

Figure 7—Height and diameter growth of green ash seedlings from 3 different nurseries either with or without chemical weed control. Weed control had a pronounced effect on seedling growth, though the ranking among nurseries was similar regardless of weed control treatment.

(Figure 2) yet the lowest survival and least field growth (Figures 5 and 7). This was in spite of the fact that seedlings from nursery A met the original morphological standards for field planting in this region (McKnight and Johnson 1980; Kennedy 1981).

The poor survival and growth observed under field conditions may be partly because of greater susceptibility of seedlings from nursery A to transplant shock incurred during the first year following planting. Transplant shock was very evident in green ash, based on the negative slope of the regression line between height and height growth as per South and Zwolinski (1996) (Figure 8). Green ash seedlings from nursery A may have had excessive shoot biomass in relation to root system size. This can act to increase initial transplant stress due to high transpirational demand from the shoot without compensatory water uptake from root systems, as has been observed previously with bareroot northern red oak (*Quercus rubra* L.) seedlings (Jacobs, unpublished data). This suggests that nursery cultural treatments (that is, sowing density, undercutting, lateral root pruning, and so on) should be designed to promote an adequate balance between shoot and root.

Our results question the validity of former seedling quality standards and call for a critical re-evaluation of morphological criteria to design new protocols for characterizing seedling quality in the LMRAV. It is likely that physiological factors and/or a combination of morphological traits may be needed to fully characterize seedling quality and outplanting response.

Chemical weed control had a relatively minor influence on seedling survival for these 2 species (though significant for water oak). However, the magnitude of the growth response differences in weeded versus unweeded plots for green ash exhibits the importance of weed control for initial plantation establishment of this species in the LMRAV. The effectiveness of chemical weed control for plantation establishment in the LMRAV has been alluded to previously (see citations in Gardiner and others 2002), and this data helps to further confirm this response. Because Federal cost-share funds are typically not provided for weed control treatments on afforestation plantings in the LMRAV, these treatments are often not employed, which may result in failed or less

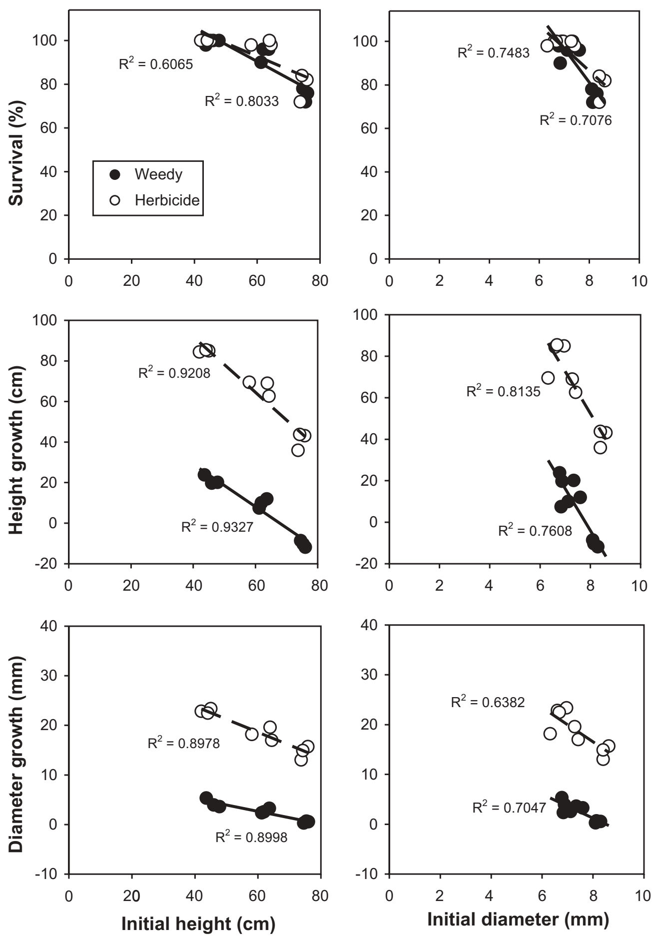

Figure 8—Regression relationships between initial height or diameter of green ash seedlings and field performance.

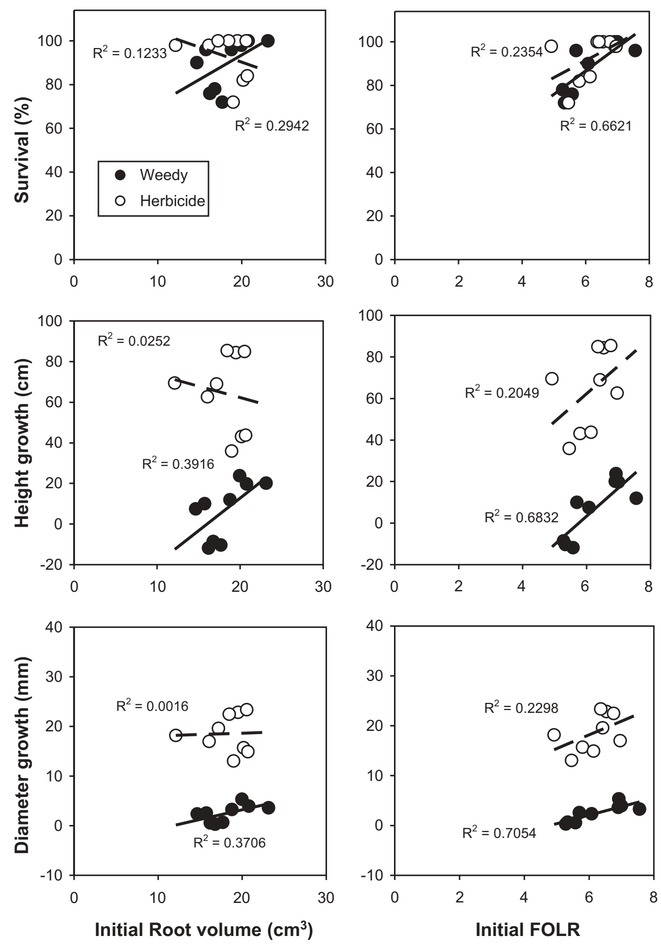

Figure 9—Regression relationships between initial root volume or FOLR of green ash seedlings and field performance.

productive hardwood plantations. Because weed control clearly promotes seedling establishment success and plantation development, we recommend provision of funds for weed control in these programs to reap benefits associated with herbicide use.

Transplant stress of 1+0 bareroot seedlings was very evident on these sites. This again suggests that further research is needed to identify nursery cultural treatments to produce seedlings that undergo minimal transplanting stress during the first growing season following planting. Generally, larger seedlings exhibited more transplant shock at least initially. We expect that growth will improve for seedlings in all treatments during the second growing season as seedling root systems become established and able to fully exploit site resources.

Future Directions

Although only a portion of the data from the study installed in 2003 was presented here, we are collecting similar data for 3 additional species across another 2 sites (totaling about 13,500 seedlings). This should provide an excellent initial data set to examine the relationship between nursery source, weed control, and seedling morphology in dictating afforestation success in the LMRAV. We installed a similar study in 2004 (about 8,000 seedlings) with several additional species to continue to broaden our scope of inference.

In the near future, we expect to solicit new cooperators and funding sources to develop a larger scale proposal to study hardwood seedling morphological quality across a larger range of sites and with a greater number of species. This proposal will promote a standardized methodology and identification of essential morphological variables for measurement. The expectation is that our data should ultimately help to establish seedling quality standards for Federal and State cost-share programs. Using this information, we expect to work with cooperators to refine nursery cultural treatments and outplanting techniques that maximize seedling performance on afforestation sites in the LMRAV.

Acknowledgments

In particular, we wish to thank State forestry agencies in Arkansas, Louisiana, and Mississippi for their interest in our research and donation of seedlings. We also appreciate important feedback from the National Resources Conservation

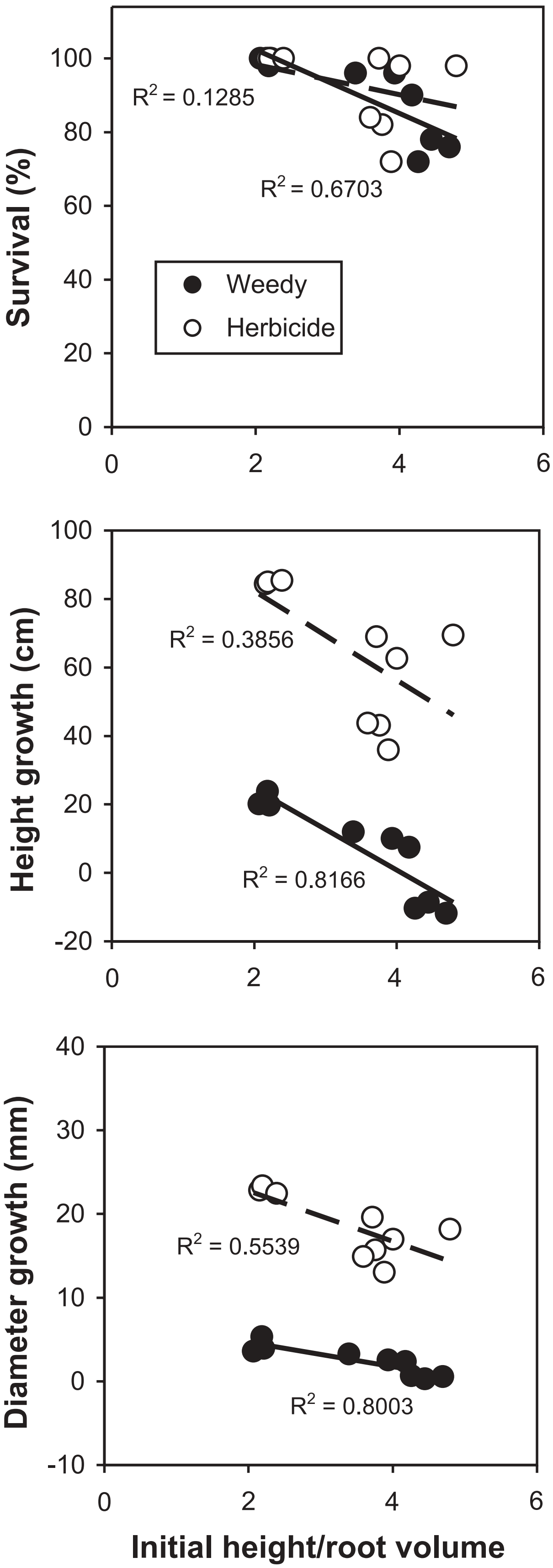

Figure 10—Regression relationship between the ratio of initial height-to-root volume of green ash seedlings and field performance.

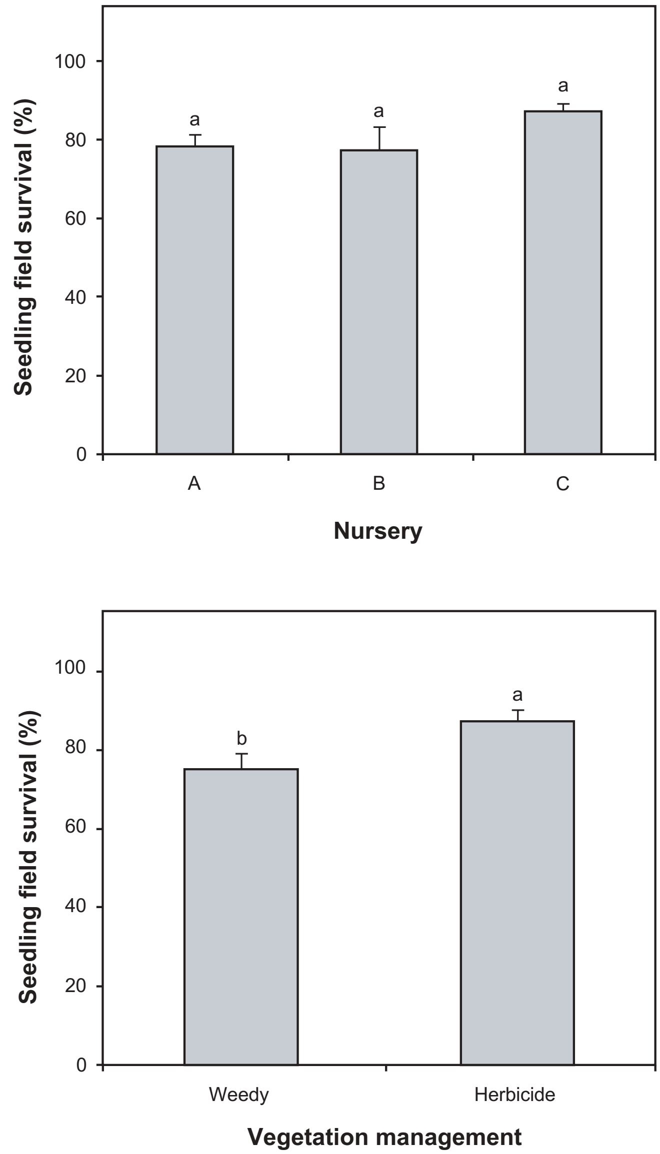

Figure 11—Water oak seedling survival by nursery and weed control treatment. For either the nursery or weed control effects, treatments with different letters above the bars are significantly different at a = 0.05.

Service (NRCS). The USDA Forest Service Bottomland Hardwoods Laboratory in Stoneville, MS, provided significant funding, personnel, and site resources to help conduct this study. This research was further funded by the USDA Forest Service State and Private Forestry and the Hardwood Tree Improvement and Regeneration Center (HTIRC) at Purdue University.

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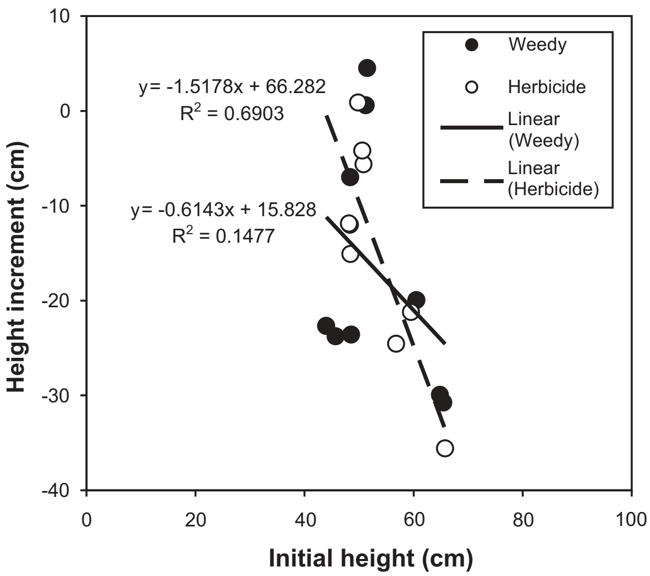

Figure 12—Regression showing initial height and field height growth for water oak. The extreme negative linear slope and tendency for negative height increment was a function of top dieback and browse pressure.

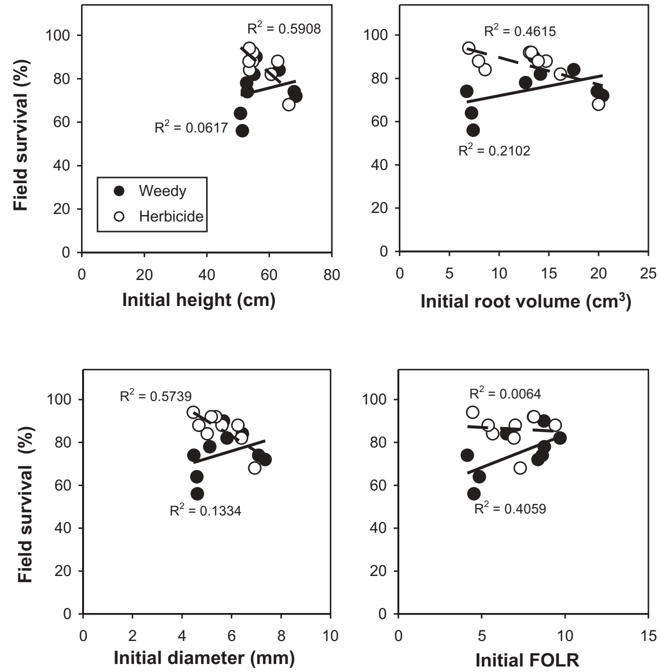

Figure 13—Regression relationships between initial morphological variables of water oak seedlings and field survival.

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Hardwood Seedling Nutrition

C. B. Davey

C. B. Davey is Professor Emeritus of Forestry and Soil Science, North Carolina State University, Raleigh, NC 27695-8008; telephone: 919.851.1168; e-mail: char1168@bellsouth.net

In: Dumroese, R. K.; Riley, L. E.; Landis, T. D., tech. coords. 2005. National proceedings: Forest and Conservation Nursery Associations—2004; 2004 July 12–15; Charleston, NC; and 2004 July 26–29; Medford, OR. Proc. RMRS-P-35. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Abstract: Hardwood seedling production presents several challenges that differ considerably from pine seedling production. Because of a nearly double water requirement, hardwoods need to be planted where they can be irrigated separately from pines. Nutrient requirements are generally higher for hardwoods, including especially nitrogen (N), phosphorus (P), calcium (Ca), and magnesium (Mg). Other nutrients are required in a slightly higher level. The form of N is very important. Sources of N that are "reduced," including ammonium and urea, are used efficiently. "Oxidized" forms, including mostly nitrate, are used less well. Requirements are usually described as how many pounds per acre of fertilizers are required. However, because the seedbed density for hardwoods is lower than that for pines, the cost of production per seedling is especially high.

Keywords: fertilization, irrigation, bareroot seedling production, mycorrhizae, sulfur

Introduction

Many years ago, at the University of Illinois, a professor named Cyril Hopkins taught nutrition of agronomic crops. Some of his students had difficulty remembering which elements were essential for plant growth. Professor Hopkins developed an easy way to remember the list. It was useful then, and despite the fact that the list is longer today than it was then, the idea is still useful. Cyril Hopkins said that he was going to open a fancy cafe. It will be known as C Hopkns, Cafe Mighty good (C HOPKNS CaFe Mg). The students could remember that, and they automatically learned that plants needed: carbon (C), hydrogen (H), oxygen (O), phosphorus (P), potassium (K), nitrogen (N), sulfur (S), calcium (Ca), iron (Fe), and magnesium (Mg). His name also includes iodine (I), but plants don't need it. Animals, including humans, need iodine.

Since Professor Hopkins came up with this idea, the list of essential nutrient elements has grown considerably longer. However, the idea has stuck and today the entire reminder goes like this:

> C Hopkns, Cafe, Mighty good, managed by cousin Mo, and Clara is the waitress (C HOPKNS CaFe Mg Mn B CuZn Mo). This shows us that carbon (C), hydrogen (H), oxygen (O), phosphorus (P), potassium (K), nitrogen (N), sulfur (S), calcium (Ca), iron (Fe), magnesium (Mg), manganese (Mn), boron (B), copper (Cu), zinc (Zn), molybdenum (Mo), and chlorine (Cl) are needed for tree seedling growth. So, the next time you are either hungry or thinking about seedling nutrition, just hurry over to C Hopkns Cafe Mighty good.

Now that we are sure that we have the complete list, we can become serious and discuss the individual nutrient elements and say somewhat more about a few of them.

Nutrient Elements From Air and Water

The main building block element in all living things is carbon. In plants, it comes from carbon dioxide in the atmosphere by way of photosynthesis. Because there is never a shortage of carbon dioxide in the field, we never worry about a carbon deficiency.

Hydrogen is the most numerous atom in all living things. Plants get their hydrogen from breaking down water into hydrogen and oxygen. They use a little of this oxygen, but most of it goes back into the atmosphere where we breathe it. Interestingly, plants also use oxygen from the atmosphere in respiration.

For many millions of years, plants got their nitrogen from the atmosphere. After all, the atmosphere is almost 80% nitrogen. Interestingly, plants, by themselves, cannot use any of that N. There are certain microbes that can convert the atmospheric N into protein N and eventually into N that is usable by plants. Since the development of the Haber process, in 1909, to convert atmospheric N into ammoniacal N, we have become mostly dependent on fertilizer N for seedling production. Thus we could say that our seedlings get their N from the soil as fertilizer N. However, in reality, it still comes from the air.

Nitrogen Fertilization

A useful comparison between pines and hardwoods is in the amount of fertilizer N required. The minimum amount of N needed by a pine crop is 150 lb/ac (168 kg/ha) while hardwoods require a minimum of 225 lb/ac (252 kg/ha). Many people apply more than these amounts, but the ratio stays about the same. That is, hardwoods take about 1.5 times as much N per acre as pines. On a per seedling basis, the ratio is closer to 3 times as much. That is because of a lower seedbed density for most hardwoods.

The N in commercial fertilizer is available in several forms. If the N is associated with oxygen, as in nitrate (NO_3), it is called oxidized N. If the N is associated with hydrogen, as in ammonium (NH_4), it is called reduced N. The N in urea is also reduced because it is associated with H. Most plants can use either reduced or oxidized N, but their efficiency of use varies tremendously.

The relative use of different forms of N by hardwoods has been studied in considerable detail (Deines 1973; South 1975; Villarrubia 1980; Auchmoody 1982). In the study by Villarrubia (1980), 7 sources of nitrogen were tested on sweetgum (*Liquidambar styraciflua* L.) and green ash (*Fraxinus pennsylvanica* Marsh.) at 3 different rates of application. Very little effect of rate was observed, but source was very important. Growth was most favorably affected by reduced sources of nitrogen. These included 2 slow-release sources of sulfur-coated urea, ammonium sulfate, ammonium nitrate, and urea. The poorest growth was associated with sodium nitrate. A polymer of urea (IBDU) was also poorly utilized. This resulted from the fact that the urea was converted to nitrate just as fast as it was released from the polymer. Thus, in effect, it was an oxidized source of N rather than a reduced source. The only study where nitrate was found to be advantageous was in the study of Auchmoody (1982). In that one case, germination of cherry seeds was favorably affected by nitrate.

Slow-release, sulfur-coated urea was compared with regular urea and ammonium nitrate by Deines (1973). Both forms of urea were superior to ammonium nitrate in producing large seedlings. The sulfur-coated urea was applied once, preplant; the regular urea and ammonium nitrate were applied in 5 split applications over the summer. The savings in cost of application of the sulfur-coated urea were offset by its higher cost. Split applications allow the nursery manager to adjust the nitrogen regime as affected by weather. This flexibility is quite advantageous.

Foliar N Concentration

Villarrubia (1980) found that foliar N concentration, in September, varied both by species and by source. In green ash, foliar N varied from 2.4% to 2.9% with ammonium nitrate, ammonium sulfate, and urea. With both sulfur-coated ureas, it was somewhat below 2%. This difference is probably attributable to the fact that ammonium nitrate, ammonium sulfate, and urea were applied in 5 split applications, whereas the sulfur-coated urea was all applied at once, preplant. Seedlings that received split applications of sodium nitrate had foliar N concentrations from 2.2% to 2.3%. That is mostly attributable to the fact that the plants were quite small. Finally, those seedlings that received a single preplant application of IBDU were both small and had a low N concentration in their foliage (1.3% to 1.7%).

The foliar N pattern in sweetgum was quite similar to that in green ash. The ammonium nitrate, ammonium sulfate, and urea all were high and ranged from 2.7% to 3.1%. The sulfur-coated ureas were again somewhat lower at 2.1% to 2.7%. The small seedlings that received sodium nitrate had foliar N concentrations of 2.5% to 2.6%. This again shows that, because the leaves were small, a little N produces a high percentage. Finally, the IBDU again produced small seedlings and their foliage contained a low concentration of N (1.3% to 1.6%).

Soil Nitrate

There are bacteria in soil that are called nitrifiers. They will slowly convert reduced N to nitrate. Villarrubia (1980) found the soil nitrate level in September varied considerably. The highest levels were associated with the 2 sources that contained nitrate. Sodium nitrate soil contained more than 50 lb/ac (56 kg/ha) of nitrate-N. Ammonium nitrate soil contained about 45 lb/ac (50 kg/ha). Urea soil was third at about 30 lb N/ac (34 kg N/ha) as nitrate. All other sources of N were below 15 lb N/ac (17 kg N/ha) as nitrate. Thus, nitrification was only mildly active in the nursery soil.

Root Collar Diameter, Seedling Height, and Seedbed Density

An important characteristic of seedling quality is root collar diameter (RCD). At lifting time, green ash showed conclusively that the nursery soil did need sulfur, as well as N. The 3 sources of N that produced seedlings with the largest RCD were ammonium sulfate and the 2 sulfur-coated ureas (Villarrubia 1980).

Despite the fact that the sweetgum seedlings were small, IBDU had the lowest seedbed density at 12.3 seedlings/ft^2 (137 seedlings/m^2). The sweetgum had the highest seedbed density (20.4 seedlings/ft^2 [227 seedlings/m^2]) with ammonium sulfate. The lowest seedbed density with sweetgum was 15.0 seedlings/ft^2 (167 seedlings/m^2) with the very slowly soluble SCU-11. High levels of fertilization did not increase height or quality of seedlings, but they did often result in lower seedbed densities. Height did vary considerably as a response to N source (Table 1).

Nutrients From Soil

Calcium

Evidence shows that hardwoods require more calcium than pines. In general, however, most nursery soils have been supplied with ample Ca. Deines (1973) tested both calcium carbonate (lime) and calcium sulfate (gypsum). A low rate of the sulfate form produced a growth response in sweetgum. He believed it was a sulfur response rather than a calcium response because there was no positive response to the carbonate form. At high levels, there was a negative response to the carbonate form, which was attributed to the adverse effect on soil pH value.

Table 1—Height of sweetgum and green ash seedlings, at lifting, as affected by nitrogen source (from Villarrubia 1980).

	Seedling height at lifting[b]	
N-source[a]	**Sweetgum**	**Green Ash**
	- - height rounded to nearest inch[c] - -	
SCU-24	26	29
SCU-11	26	28
Urea	25	29
Ammonium sulfate	24	30
Ammonium nitrate	24	29
IBDU	18	27
Sodium nitrate	15	22
Average	**23**	**28**

[a]N source abbreviations: SCU-24 is sulfur-coated urea that releases N at a moderate rate; SCU-11 is sulfur-coated urea that releases N at a very slow rate; IBDU is isobutylidene diurea, which is a slow-release polymer of urea.
[b]Seedling height was not significantly affected by rate of N application. Thus the heights in this table are the averages of all rates.
[c]Conversion: 1 in = 2.5 cm.

Potassium

Studies in 2 nurseries with contrasting soil (Deines 1973) showed that potassium was needed, but its source was not important. Where K was needed, either the chloride or the sulfate source was satisfactory. The sulfate source gave some better growth than the chloride source, but again it was apparently a sulfur response.

Magnesium

Increasing applications of ammonium nitrate reduced Mg uptake by sweetgum at 2 nurseries (Deines 1973). Also, high levels of ammonium nitrate reduced the foliar content of K and Ca.

Mycorrhizae

In a study of endomycorrhizal inoculation of fumigated nursery soil, South (1975) reported an improvement of mycorrhiza formation from inoculation. However, there was a reduction of mycorrhiza formation when a high level of phosphorus was applied to sweetgum and sycamore. Trees that are endomycorrhizal are likely to suffer a lack of mycorrhiza formation because of over-fumigation of the soil. This is because the inoculum spores are soil-borne and thus are slow to reinfect soil. Spores of the fungi of ectomycorrhizal tree species (pines and oaks, for example) are air-borne and can reinfect the soil much more quickly. In a study by Danielson (1966), inoculum for pines was introduced from a pine straw mulch and from the air. Mycorrhiza formation was delayed by only a few weeks with loblolly pine. From personal observation, it can be reported that endomycorrhizal fungus reintroduction, without intentional inoculation, requires more than a year. Using pine straw mulch on the beds of hardwood seedlings greatly increased the amount of hand weeding needed, but it did not increase the endomycorrhizal fungus inoculation (South 1975).

Outplanting Study

In an outplanting study with green ash, tall seedlings from the nursery grew well in the field. The small seedlings that received IBDU or sodium nitrate grew the poorest in the field in the first year (Villarrubia 1980). With hardwood seedlings, it seems that bigger is better.

Conclusions

- The low (normal) rate of N tested was as effective as the highest (3X normal) rate. Thus, the nursery manager can save money by not applying excess fertilizer.
- The N sources tested fell into 2 groups. The sodium nitrate and the IBDU were each poor N sources. Despite some small differences, all other sources were useful.
- Ammonium sulfate and SCU-24 produced rapid early growth of the seedlings. They captured the bed quickly and reduced weeding costs.
- Soil acidity changes were complex. As expected, acidification with ammonium sulfate was greatest. Acidification was correlated with rate. The IBDU and S-coated ureas, which were plowed down, produced early and strong acidification. However, this decreased with time. The sodium nitrate changed the soil from being slightly acidic to alkaline.
- Foliar N concentration was highest with the sources that were used in split applications. The IBDU was lowest. It was applied preplant and was used poorly. Foliar N concentration increased with rate, regardless of source or species. Some of this was undoubtedly luxury consumption.
- Nitrogen sources that contained sulfur were superior to those that didn't. Thus, in most soil, sulfur was needed. The sulfur containing sources produced an early start in growth and a rapid bed capture.
- In sweetgum and green ash, Villarrubia (1980) reported the following in regard to the effect of the various N sources on the concentration of foliar nutrients:

1. N: Sodium nitrate and IBDU were not satisfactory N sources. All other sources tested were satisfactory.
2. P: Sodium nitrate resulted in poor P uptake. All others were satisfactory.
3. K: Sodium nitrate resulted in high foliar K concentration. Other N sources varied slightly in their effect on K uptake. In general, as the N application rate increased, foliar K concentration decreased.
4. Ca: Sodium nitrate resulted in the lowest foliar Ca concentration. IBDU resulted in the highest.
5. Mg: Sodium nitrate resulted in the lowest foliar Mg concentration. The other N sources were satisfactory.
6. Sulfate S: Ammonium sulfate, as expected, resulted in the highest foliar sulfate concentration.

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Survey of Root and Shoot Cultural Practices for Hardwood Seedlings

Harry L. Vanderveer

Harry L. Vanderveer is Manager, Nursery Operations, Texas Forest Service, PO Box 617, Alto, TX 75925-0617; telephone: 936.858.4204; e-mail: hvanderveer@tfs.tamu.edu

In: Dumroese, R. K.; Riley, L. E.; Landis, T. D., tech. coords. 2005. National proceedings: Forest and Conservation Nursery Associations—2004; 2004 July 12–15; Charleston, NC; and 2004 July 26–29; Medford, OR. Proc. RMRS-P-35. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Abstract: A telephone survey of selected forest seedling nursery managers was conducted in early 2004. About 2 dozen managers were contacted and asked to respond during a brief (15 to 30 minute) conversation about the current practices they employ to manage root and shoot growth of hardwood seedlings. The participants involved were evenly split between public agencies (government) and private agencies (forest industry or other corporate entities). To receive open and honest responses to all questions, individual nursery names, locations, and managers were kept confidential.

Keywords: root pruning, undercutting, top clipping, shoot pruning, root wrenching, shoot-to-root ratio

Introduction

The efficient production and culturing of forest tree seedlings for reforestation, or even afforestation, of land in the United States has attracted broader interest in recent years, with a stronger emphasis on the benefits these trees bring to wildlife, watersheds, and the esthetic values of the landscape. Large-scale efforts are ongoing for most of the major conifer species, which are usually managed for forest products uses, including lumber and paper production. In contrast, hardwood species are now being grown to meet different objectives. These are often smaller-sized planting sites with specifically intended outcomes, such as wildlife habitat improvement for hunting, viewing, or, in some cases, replenishing threatened or endangered species. This emerging interest in hardwood seedling production has stimulated the need to compile the current state of knowledge and practices for producing the wide variety of hardwoods grown in a more effective and efficient manner.

The objective of this survey was to determine what types of activities nursery managers use to manipulate the growth and development of plant roots and shoots. Other investigators at this conference gathered information on the current state of knowledge and practices for hardwood seedlings in the areas of soil fertility and plant nutrition, crop rotation, cover cropping, and weed management.

Methodology

In May 2004, a list of forest seedling nurseries was reviewed to find those that currently grow hardwood seedlings. An effort was made to contact a sampling of those nurseries across the southeastern and northeastern areas of the United States. Approximately 24 nursery managers from these regions were eventually contacted. Roughly half of these managers worked for public agencies (state nurseries), and half were employed by private sector enterprises. These private nurseries were again split between large forest industry corporate nurseries, small nursery companies, and family-operated businesses. Ultimately, nurseries in Alabama, Arkansas, Florida, Georgia, Indiana, Louisiana, Maryland, Missouri, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, Virginia, and Wisconsin were contacted.

After initial contact with these nurseries, it was determined that participants in the survey would speak most freely and frankly if their actual employer affiliation remained confidential.

Survey Questions and Discussions

The survey questions and discussions were categorized into these topic areas:

1. Why do you culture your hardwood seedlings?

2. Do you use any special equipment to accomplish the culturing procedures?

3. Are there any special considerations for culturing hardwood seedlings?

4. What pitfalls have you learned to avoid when culturing hardwoods?

Culturing Hardwood Seedlings

The most common response was "to meet customer specifications." An alternative response was "to have more uniform seedlings." Further questioning on this topic revealed that proper shoot-to-root ratio was deemed important. The need to facilitate seedling harvesting and packaging was also mentioned by several nursery managers as a reason to manipulate the shoots and roots of seedlings.

Figure 1—Stationary blade used to undercut root systems in bareroot seedling beds.

Special Equipment Used to Culture Hardwoods

The equipment question naturally divided between root culture and shoot culture. For root culturing, 3 types of devices were most often mentioned by nursery managers. A stationary, sharp blade that is drawn behind a tractor is commonly used to undercut root systems in the nursery seedbeds (Figure 1). Some nurseries like to use a more intricate and costly reciprocating undercutting blade implement (Figure 2). Each of these types of undercutters can accomplish acceptable manipulation of the depth of root development.

For managing the lateral roots of hardwood seedlings, either a series of rolling coulter blades positioned to run between the drills of growing seedlings (Figure 3), or a set of stationary knife-like blades drawn between the seedling drills is used. However, it should be stated that nursery managers did not universally do lateral root pruning of hardwoods. The reason for this was divided: (1) any disturbance to, or reduction in, the mass of lateral roots is detrimental to survival and growth of hardwood seedlings; and (2) some nurseries do not own lateral root pruning implements.

Management of seedling shoots requires a totally separate assortment of equipment. Most commonly employed for this purpose is a rotary mower or brush hog (Figure 4). Several of the nurseries contacted use sickle-bar clippers (Figure 5) to limit the height growth of hardwood seedlings. They cited the more surgical cutting action and better visibility as the reasons for choosing this tool. Finally, a few nurseries that only occasionally do top pruning of hardwoods said they tried gasoline powered hedge trimmers.

Special Considerations for Culturing Hardwood Seedlings

The nursery location and climate conditions were often mentioned as factors that determine when seedling cultural

Figure 2—Reciprocating blade used to undercut root systems in bareroot seedling beds.

Figure 3—Rolling coulter blades used to manage lateral roots in bareroot seedling beds.

Figure 4—Rotary mower used to manage seedling shoot growth in bareroot seedling beds.

activities can be performed. Soil and weather conditions are always part of the decisionmaking process around a seedling nursery. This seems to be where experience and knowledge of local conditions become very important in managing a seedling crop. Possibly this is when the science and art of nursery production part ways?

The next most frequently referenced consideration was the customer type—whether they are buying trees for reforestation use or liner stock for ornamental nursery production. The size and shape of seedlings going to the horticultural trade is far more demanding in terms of seedling height, caliper, and quality of the root systems. Generally, these plants are larger than reforestation grade plants. Of course, the pricing for seedlings entering this part of the market tends to be considerably higher than those sold for reforestation.

Figure 5—Sickle-bar clippers used to manage shoot growth in bareroot seedling beds.

Pitfalls to Avoid When Culturing Hardwoods

Pitfalls or practices to avoid in the culturing of hardwood seedlings probably came to light from a big problem that a nursery manager encountered in the past. The range of responses to this particular discussion question ran the gamut from "we never top-prune or root-prune" all the way to "we top-prune early and often." Again, the customer usually determines which of these extremes is practiced. A few items that were mentioned by several survey contacts included: (1) don't top-prune seedlings of opposite budded species, such as maple, ash, and dogwood; (2) top clip tender, green growth and avoid cutting into hardened, woody stems; and (3) produce a plant that does not require any additional field pruning of either shoots or roots.

Summary

Hardwood seedlings vary a great deal. Different species, different customer expectations, different soils, varying climate conditions, various availability of special nursery equipment, and the range of experiences and personalities of nursery managers make generalizations on the subjects of root and shoot pruning very difficult. The topics deserve a more thorough treatment in terms of fact-finding on the currently observed methods and scientifically based investigation. With the growing interest in producing hardwood seedlings, a forum should be convened to advance the accumulated knowledge and understanding on these important topics. This information could then become a basis for better plant production and education for the future generations of nursery practitioners.

Panel Discussion: Using Shielded Sprayers to Control Weeds in Nursery Beds

Dwight H. Stallard

Dwight H. Stallard is Nursery Manager, Virginia Department of Forestry, Garland Gray Forestry Center, 19127 Sandy Hill Road, Courtland, VA 23837; telephone: 804.834.2855; e-mail: dwight.stallard@dof.virginia.gov

In: Dumroese, R. K.; Riley, L. E.; Landis, T. D., tech. coords. 2005. National proceedings: Forest and Conservation Nursery Associations—2004; 2004 July 12–15; Charleston, NC; and 2004 July 26–29; Medford, OR. Proc. RMRS-P-35. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Abstract: Shielded sprayers have proven to be more effective than mechanical-type machines at controlling weeds in hardwood crops. Hand weeding times are reduced significantly, lowering costs and saving time for nursery personnel to do other jobs.

Keywords: Roundup™, Egedal, MTDC, Goal™, herbicides, bareroot seedlings

Controlling weeds in hardwood nursery crops has always been a major problem for nursery managers due to the lack of effective herbicides that will kill the weeds without damaging the crop. With the realization that the potential loss of methyl bromide could make the problem even worse, the Virginia Department of Forestry (VDOF) began looking at alternative methods of weed control in the late 1990s.

Mechanical cultivators, such as the brush hoe and triple share cultivators that would physically remove the weeds between drill rows, were purchased and tested. Although these pieces of equipment were helpful in removing weeds, they had drawbacks. Some weeds that were disturbed managed to live, and we felt that damage was occurring to fine feeder roots of crop plants. The violent spinning action of the brush hoe created dust and visibility problems for the operators and any small error in alignment would result in damaged seedlings.

As a result of our less than complete satisfaction with these units, we decided to purchase a shielded sprayer that could be used to apply Roundup™ directly to the weeds between drill rows. At the time, the only shielded sprayer (Figure 1) known to us was made by Egedal, a company based in Denmark. We purchased the unit and began testing it, tentatively at first, until we were comfortable that we would not kill the seedlings as well as the weeds. Roundup™ is a non-volatile chemical that does not produce vapors that can drift around and damage susceptible vegetation nearby. The shields prevent the spray from escaping and damaging seedlings. A row marker is suspended directly over the outside drill row to allow the tractor operator to keep the sprayer running properly between rows. The unit also has an operator seat and steering bar to help keep the unit lined up in the rows. An added benefit to using shielded sprayers over mechanical weed removal is that weeds growing in the drill row that extend some foliage into the inter-row spaces receive enough spray to eliminate them.

The VDOF has also cooperated in the testing and development of a shielded sprayer (Figure 2) designed and constructed by Keith Windell of the USDA Forest Service Missoula Technology Development Center (MTDC) (see also Vachowski, this proceedings). Mr. Windell and VDOF personnel tested his sprayer at the New Kent Forestry Center. After a few changes, the unit is now located at the VDOF Augusta Forestry Center where it is working fine. The sprayer has specially constructed shields that can be adjusted to varying widths, allowing the sprayer to be used in seedbeds having 4 to 8 drill rows. As part of the MTDC effort at technology transfer, this sprayer is available for others to try. Contact the author for more information. Design specifications and drawings will soon be available on the MTDC Web site allowing others to build their own sprayer if they desire.

The VDOF currently uses the shielded sprayer to assist in weed control in hardwoods in the following manner. In any seedbeds where our initial spray schedule of other herbicides has failed to adequately control the weeds, which occurs all too frequently, Roundup™ is applied to all inter-row areas and to the tractor paths using the shielded sprayer. An application of Vantage® or other grass control herbicide is applied to the beds to remove grasses from the drill rows where Roundup™ is not effectively applied. After these 2 applications are allowed to work, the beds are hand weeded until the beds are free of weeds. To prevent weeds from returning, Goal™ is applied to the beds of oak and other large-seeded species using the shielded sprayer at the monthly rate for Goal™ use. This method will take care of severe weed problems and usually allows the seedbed canopies to close in, preventing more weeds from getting started.

Figure 1—Egedal shielded sprayer used to spray Roundup™ directly to weeds between drill rows.

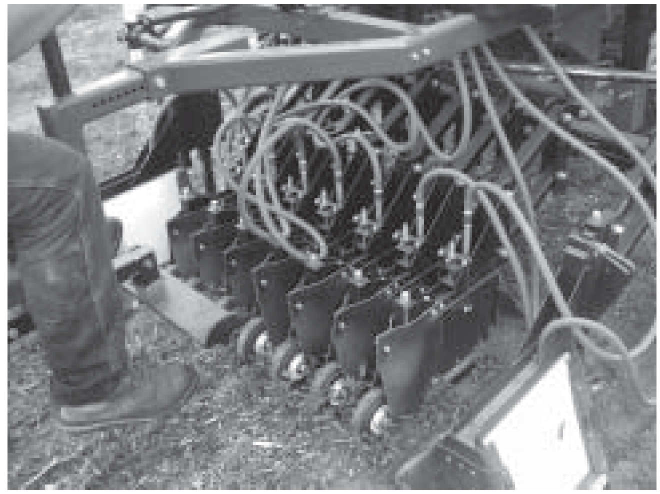

Figure 2—Shielded sprayer designed by USDA Forest Service Missoula Technology Development Center.

VDOF has found the use of shielded sprayers to be a highly effective tool in the constant battle to keep hardwood seedbeds free of weeds. Our hand weeding time has been significantly reduced, which has lowered our costs. If methyl bromide is lost, tools of this type will be absolutely necessary to control weeds in both hardwood and conifer seedbeds.

Container Hardwood Seedling Production

John McRae

John McRae is Operations Manager, International Forest Company, 1550 Simpson Road, Odenville, AL 35120: telephone: 205.629.6461; e-mail: jmcrae@interforestry.com

In: Dumroese, R. K.; Riley, L. E.; Landis, T. D., tech. coords. 2005. National proceedings: Forest and Conservation Nursery Associations—2004; 2004 July 12–15; Charleston, NC; and 2004 July 26–29; Medford, OR. Proc. RMRS-P-35. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Abstract: Container production of hardwood seedlings requires larger cavities, more space, and the ability to easily sort seedlings (as compared to conifers) very early during the germination phase of production. This presentation demonstrates the most productive system, based upon past experience, to commercially produce container hardwoods. The container system of choice is called "Old Native Tube" or "Vic Pots" and was developed and manufactured in Australia. Seedling target sizes are 18 to 24 in (45 to 60 cm) in height and 5 to 7 mm root collar diameter (RCD).

Keywords: Vic Pots, sorting, seed quality

Introduction

International Forest Company introduced commercially produced container hardwood seedlings to the Southeastern United States market in the early 1990s (McRae 1999). Details of production techniques and costs compared to bareroot seedlings have already been reported (McRae and Starkey 2002). This presentation focuses on container and media revisions since the 1990s.

Container Production

Container Types

Early production of container hardwood seedlings occurred in Hiko V-93 containers. Although the seedlings grew very well, usually in excess of 18 in (45 cm), the root-to-shoot ratio was often out of proportion. Outplanting survival was not affected by this ratio imbalance, which was likely due to the excellent quality root establishment as a result of our growing techniques. However, height growth after outplanting was often less than desired. To create a better ratio, production was changed to the Ray Leach™ system, using 115 cc (7 in^3) tubes. These were easily sorted to accommodate noticeable germination and subsequent growth rate variability that was traced to seed size. Better yield (more quality seedling production) resulted, as well as increased height growth after outplanting. However, the system was expensive to use, primarily during the media filling operation. Also, we still desired a larger cavity. A Styroblock™ product (Superblock 60/220 ml [13 in^3]) was used to facilitate media filling. A better root-to-shoot ratio was obtained, but the seedlings were very difficult to extract and sort by size during the germination phase. This operation (sorting by size) is crucial to our success of increasing the yield of our shippable products.

Seed Size and Quality

Seed size and quality, especially among oak species, have a tremendous influence on speed of germination as well as subsequent growth rates. Proper moisture content is, of course, crucial to uniform germination. Assuming filled live seeds are sown also plays a large role in container production. Inevitable significant germination and growth rate variation make it difficult to obtain uniform stands that are critical to efficient production required for container seedling success. Seed quality remains a significant issue that all growers must understand; adjustments in growing techniques are employed to maximize yields within individualized restraints. The effects of seed size are evident within 19 days of sowing, resulting in seedlings as tall as 9 in (23 cm) adjacent to many acorns from the same species and seedlot that have yet to initiate hypocotyl growth (Figure 1).

After observing successful production of rooted cuttings in "Vic Pots" by Boise Cascade personnel in Los Angeles, CA, we surmised that this system would best suit our needs as well. This container system, also referred to as "Old Native Tube," is manufactured in Australia. The tray system is composed of 3 parts: (1) the tray, (2) tube inserts, and (3) a bottom drip

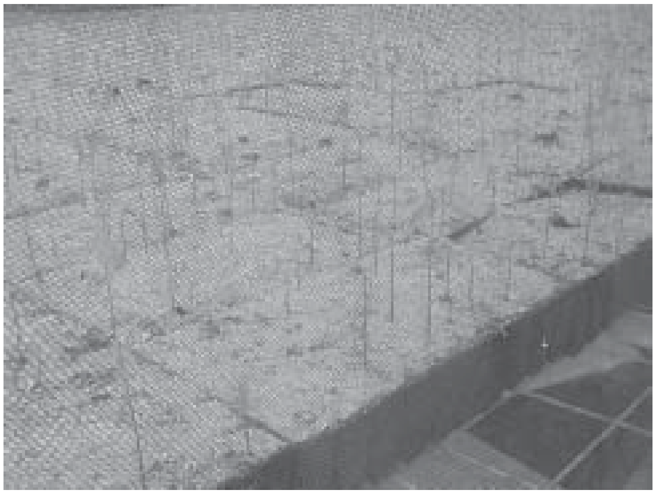

Figure 1—Oak seedlings showing variations in height growth initiation 19 days after sowing.

Figure 3—Oak seedlings grown in "Vic Pots" and sorted by size 30 days after germination.

rail that snaps on the tray bottom to aid air pruning and media drainage (Figure 2). The tray holds 50 cavities that are flush mounted, which facilitates mechanized media filling very well. They are square tapered tubes containing ribs that perfectly guide root growth downward. The cavity is 15 in^3 (240 cc), 5 in (13 cm) deep, 2.5 in (6 cm) across the top that tapers to 2 in (5 cm) at the bottom containing a double "cross hair" to help media retention. The cavity density is 22 cavities/ft^2 (244 cavities/m^2) (as compared to the HikoV-93 tray of 49 cavities/ft^2 [544 cavities/m^2] and typical bareroot production of 10 to 12 seedlings/ft^2 [111 to 133 seedlings/m^2]).

This large cavity allowed us to change our media mixture to include hammered peat moss and fine vermiculite to enhance moisture retention which, in turn, provided greater flexibility in our watering regimes. Also, as a standard practice, we add Banrot® 8G and a Polyon® 4-month controlled release fertilizer to the media.

Figure 2—"Vic Pot" 50 cavity tray with drip rail.

This system allowed seedling sorting very early in the germination phase without disturbing the roots, thereby increasing our seedling yield and quality. Seedlings 8 to 12 in (20 to 30 cm) in height after 30 days were removed from the trays and transferred to alternating cavities in new trays (Figure 3). The consolidated shorter seedlings had more space to grow vigorously into shippable products. Based on results thus far, we expect a 50% greater yield of quality seedlings, resulting in vigorous growth after outplanting as compared to production in Hiko V-93 trays. Seedling target sizes remain 18 to 24 in (45 to 60 cm) in height and 5 to 7 mm root collar diameter.

Summary

Based upon the results of 2 seasons, International Forest Company will continue to employ the "Vic Pot" growing system to produce hardwood container seedlings. Hardwood seed quality will always remain a critical issue. Hence, nearly any physical improvement that can be made that results in greater uniformity will certainly be researched and then employed where success is evident.

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Use of Cover Crops in Hardwood Production

Randy Rentz

Randy Rentz is Nursery Manager, Louisiana Department of Agriculture and Forestry, Columbia Forest Nursery, 276 Columbia Nursery Road, PO Box 1388, Columbia, LA 71418; telephone: 318.649.7463; e-mail: rrentz@ldaf.state.la.us

In: Dumroese, R. K.; Riley, L. E.; Landis, T. D., tech. coords. 2005. National proceedings: Forest and Conservation Nursery Associations—2004; 2004 July 12–15; Charleston, NC; and 2004 July 26–29; Medford, OR. Proc. RMRS-P-35. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Keywords: bareroot seedlings, organic content, weed control

Cover crops are as essential a practice in hardwood production as in pine production or any other nursery operation. Without proper cover crop rotation in a nursery plan, we open ourselves up to an array of problems: more diseases, wrong pH, more weeds, reduced fertility, and less downward percolation of soil moisture due, in part, to compaction.

Proper cover cropping is probably the single most important thing we can do to enhance seedling health and vigor. Without reasonable organic matter content in the soil, we spend more on fertilization, disease control, and irrigation. Soil tilth, cation exchange capacity (CEC), and moisture retention begin to be problems. This in turn leads to pH, fertility, and disease problems, which in turn lead to poor root systems and poor seedling quality. Organic material in the soil is in a constant state of decay. This means it must be renewed constantly by the addition of plant residue. It is the main source of soil microorganisms, thus keeping biochemical activity constant in the soil. We keep organic material renewed in 2 ways: (1) by the addition of plant and animal residue, and (2) by the growing and maintenance of cover crops.

The program we use in cover crops is quite simple. On a 2:2 rotation (2 seedling crops, then 2 cover crops), we start with corn in the first spring following seedling lifting. This is followed by winter wheat and then by sudex, which is cut under with 2 in (5 cm) of cotton gin trash in August and September in preparation for fumigation in the fall. Sunflowers can also be a very good cover crop, but can also become weeds if we aren't careful. Many cover crops can be harvested and sold. They can also provide a continuous source of seed for the next crop.

The soil at Columbia Nursery (Columbia, LA) and Monroe Nursery (Monroe, LA) are both silt loams. Monroe Nursery has soil that is a little tighter, with shallower topsoil and heavy clay subsoil. The high lignin content and deep root systems of the mix of cover crops work very well in these soils. These help in the granulation and maintenance of the soil, not only chemically and biologically, but physically as well.

Cover crops, and thus organic material, are possibly even more important in sandy soils due to its lack of capacity to absorb and hold sufficient moisture and nutrients. The only way to improve the soil structure is with the addition of organic matter. Organic material increases the ability of the soil to retain nutrients, acts as a binding agent, and increases its water holding capacity.

Cover crops act as weed control in 2 primary fashions. Cover crops shade out any potential weeds; it is best to over-seed all crops to assure an adequate stand and full coverage to prevent any possibility of a weed problem. In addition, a wider range of chemicals can be used on cover crops to control a wider variety of weeds. This helps prevent a particular weed from becoming resistant to a chemical and allows better control of historically hard-to-handle nursery weeds, such as yellow and purple nutsedge, spurge, primrose, and morning glory. This is especially true in a hardwood nursery where our chemical controls are somewhat limited. Also, with a 2:2 rotation, chemicals that may have a little residual can be used in the first year after seedlings without having an effect on the next seedling crop. If at any point there is a weed problem in the cover crop, it should be cut under, treated, and replanted. It is very important that a weed control program be utilized along with all cover crop rotations.

Everyone knows the advantages of high organic matter content in the soil. Low organic matter creates a myriad of problems. It is just so much easier to grow a crop with an acceptable organic matter content. It takes less irrigation, less fungicide, less fertilization, less fumigation, less tillage and can, when done properly, take less herbicide and manpower. With proper rotation of cover crops, high organic matter content can be obtained and sustained. A 2:2 rotation is preferred because it allows 3 different crops before every seedling crop: corn and sunflower for high lignin; wheat for deep penetrating roots; and sudex for lignin and mass. This rotation also allows us to work on any field with problem areas for 2 years before going back in with seedlings.

If for any reason a cover crop is not taken just as seriously as a seedling crop at a nursery, it would be wise to readjust the thought process and consider the advantages of a good, well maintained program.

Panel Discussion: Application of Living Mulch for Spring-Sown Loblolly Pine

Paul Ensminger

Paul Ensminger is Nursery Manager, Woodlands Specialists, Inc., 11306 Highway 411 S, Chatsworth, GA 30507; telephone: 706.334.2271; e-mail: pensminger@mail.state.tn.us

In: Dumroese, R. K.; Riley, L. E.; Landis, T. D., tech. coords. 2005. National proceedings: Forest and Conservation Nursery Associations—2004; 2004 July 12–15; Charleston, NC; and 2004 July 26–29; Medford, OR. Proc. RMRS-P-35. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Keywords: bareroot seedling, cover crops, herbicides

Those who grow hardwood seedlings are familiar with fall sowing seeds and using rye, wheat, or oats to over-winter the crop. Throughout this paper, reference to rye is GRAIN, NOT GRASS (do not use rye grass). The rye stabilizes and insulates the beds while retarding predation and weeds. Normally sown at 2 bushels/ac (5 bushels/ha), the rye is killed with Roundup™ before the seeds germinate (around mid-February), allowing the seeds to germinate and emerge unimpeded. Light-seeded, fall-sown hardwoods often necessitate only 1 bushel/ac (2.5 bushels/ha).

As an outgrowth of this, we experimented in 1999 on 9 beds using an application rate of 2 bushels rye/ac (5 bushels rye/ha) for spring-sown loblolly pine (*Pinus taeda*). The results were so favorable that we expanded to 0.5 ac (0.2 ha) in 2000. Finding no problems, we expanded this application to half our loblolly pine crop in 2001.

The use of pine bark mini-nuggets on our whole loblolly pine crop in 2001 would have cost us approximately U.S. $30,000. The same area using the rye would have cost us U.S. $400. An equally important savings is the application time. A broadcast seeder can cover 5 beds with 1 pass; the more conventional bark application requires 1 pass per bed with a manure spreader that must return to the bark pile to be loaded between applications.

There were several unanticipated findings:

1. There seemed to be some positive partial shading of seedlings in early days.
2. No mulch floated off.
3. There were no introduced weeds (as would have occurred with mulch).
4. The weeds were shaded out by the rye.
5. Rye can stand Goal™ pre-emergent to a degree. We generally did not use Goal™ when using rye.
6. The dead thatch lasted until crown closure.
7. The seedlings achieved the same density as those grown without the living mulch.
8. The seedlings were the same quality at lifting as those grown without the living mulch.
9. As a cover crop, rye was better than oats, which was better than wheat.

A negative finding was that the seedlings were about 2 weeks behind in reaching crown closure. We attributed that to nitrogen deficiency caused by microbial action on decaying rye root systems.

Other uses of living mulch include stabilization of the sawdust applied over sown pine seed and the over-wintering of white pine (*Pinus strobus*) between the 1+0 and 2+0 years. (**When killing the rye before the spring growth of the 2+0 white pine, it is important to mow the rye at "Tree-Top" level approximately 3 days after herbicide application but before it falls over. This will prevent a thatch from forming over the top of the seedlings. The winter rye will be tall and present an impenetrable thatch if this is not done.**)

The steps for using living mulch on spring-sown loblolly pine are:

1. Level the ground.
2. Broadcast the rye at an application rate of 2 bushels/ac (5 bushels/ha).
3. Build the seedbeds.
4. Sow the pine seeds.
5. Kill the rye with Poast®. Although it may appear that the rye is too abundant when viewed from ground level, an overhead view would show that this is not so. It is all right if the rye is taller than the seedlings as long as the dead rye does not form a thatch over the seedlings when it falls over.
6. The pine seeds must be covered with soil or at least pressed in.

Some alternatives to consider:

1. Wait 2 to 3 days after building beds to sow pine seeds to give the rye a head start in germination and growth.
2. If you decide to use Goal™ pre-emergent, increase the rye to 3 bushels/ac (7.5 bushels/ha) and/or sow the rye after the bed is formed instead of before. The rye germinates very poorly if it is not covered or pressed in.

Panel Discussion: Cover Crops Used at Vallonia Nursery, Indiana Division of Forestry

Robert Hawkins

Robert Hawkins is Operations Manager, Vallonia State Nursery, Indiana Division of Forestry, PO Box 218, Vallonia, IN 47281; telephone: 812.358.3621; e-mail: bhawkins@dnr.state.in.us

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Keywords: bareroot seedlings, organic content, living mulch

The use of cover crops is one essential step in management of nursery soils. Cover crops serve many different purposes within the soil. First, cover crops help in reducing erosion by stabilizing soil. Second, cover crops can be used as a visual guide to nutrient deficiencies in fields prior to sowing seedling crops. Most important, cover crops build organic matter, which has a positive effect on seedling growth.

Organic matter helps to reduce the buildup of damping-off fungi, which could infect the emerging seedlings. Organic matter also affects soil texture, water-holding capacity, nutrient availability, cation exchange capacity (CEC), soil pH, and the presence and functions of microorganisms that are usually beneficial for seedling growth. In our sandy soils, every 1% buildup of organic matter can release up to 75 lb/ac (84 kg/ha) of nitrogen that can be used by the plants.

Standard Cover Crops

We typically use grass cover crops as opposed to legumes because grass cover crops do not build up as much damping-off fungi as legume crops. The types of cover crops used in our nursery are as follows: Roundup Ready® corn, Concept-treated sorghum, sorghum-sudan grass, wheat, and rye.

The Roundup Ready® corn and Concept-treated sorghum allow chemicals to be used at planting time or during the growing season to help keep the fields cleaner prior to fumigation. All cover crops are grown until they must be tilled before fumigation. We generally start flail mowing cover crops August 1 (Figure 1) in order to fumigate on or around September 1. Disking, chisel plowing, and ripping are all done to help incorporate cover crop residue.

Living Mulch Cover Crop

Part of the acreage at the nursery is used to grow rye and wheat to be harvested for the seeds and straw. The straw is used to cover all oak, black walnut, and hickory seedbeds for winter protection. In Indiana, a normal winter has cold temperatures (0 to 10 °F [-18 to -12 °C]) with little or no snow for insulation. The beds are covered by 3 in (8 cm) of straw to protect seeds from extreme cold temperatures. The harvested rye is sown at the same time as the tree seeds on all seedbeds. This prevents seedbed erosion and provides protection of all seeds during the winter months. Along with the straw, this dense mat of rye provides protection to the seeds from deer and squirrel predation. The wheat seeds are used to cover all costs incurred from the harvesting of the rye and the bailing of straw by a local farmer.

In late winter or early spring, the rye is sprayed and killed before emergence of tree seeds. Depending upon timing of the application, paraquat or Roundup™ can be used for a quick burndown of the rye as well as any winter annuals that might be present (Figure 2). This can only be used before seedling emergence. After seedling emergence, Fusilade® is used to kill the established rye over the seedbeds.

After the rye has been killed, the straw is removed by means of a controlled burn (Figure 3). Removal of all straw may require the field to be burned more than once. The burning is quick and does not get hot enough to damage exposed seeds. I do feel that you would want to burn before the seeds start to emerge from the ground to avoid seedling damage. All fire can be extinguished by the use of the irrigation system if necessary.

Figure 1—Flail-mowing of corn cover crop at Vallonia Nursery.

Figure 2—Established rye killed with herbicides before seedling emergence.

Figure 3—Rye straw removed from seedbeds with a controlled burn.

The rotation normally used at the Vallonia Nursery is 1 year in wheat/rye, 1 year in corn/sorghum, and then 1 year in seedling production. All ground is fumigated prior to sowing for seedling production.

Panel Discussion: Cover Crops Used at Georgia Forestry Commission Flint River and Walker Nurseries

Jeff Fields

Jeff Fields is with the Georgia Forestry Commission, PO Box 819, Macon, GA 31202; telephone: 478.751.3250; e-mail: jfields@gfc.state.ga.us

In: Dumroese, R. K.; Riley, L. E.; Landis, T. D., tech. coords. 2005. National proceedings: Forest and Conservation Nursery Associations—2004; 2004 July 12–15; Charleston, NC; and 2004 July 26–29; Medford, OR. Proc. RMRS-P-35. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Keywords: bareroot seedlings, organic content, rye, wheat, sorghum sudan grass

Cover Crops Used at Flint River and Walker Nurseries

Flint River Nursery, located near Montezuma, Georgia, has used rye, wheat, brown top millet, and sorghum sudan grass for cover crops. Flint River has just begun to return to a summer cover crop situation.

At Walker Nursery, located near Reidsville, Georgia, certified rye has been sown by the State Department of Corrections (DOC) for their harvesting, with a benefit to both DOC and the nursery. They prepare land, plant, fertilize, spray herbicides and harvest the rye. Generally, no summer cover crop is sown at Walker.

Methods and Rates of Application at Flint River Nursery

We are generally on a 2:2 rotation (2 seedling crops, then 2 cover crops) where practical. We will grow a crop for 3 consecutive years on a particular field before it is harvested and planted into cover crop. Quality generally is greatly reduced in the third year.

Our soil organic matter content has been generally pretty low in the past, but has increased significantly over the past year. Sudan grass provides us with the most increase in organic matter, as well as the most coverage and, therefore, the most shading or choking-out of nutsedge and other weeds. Nutsedge, particularly purple nutsedge, is the hardest weed to control and our biggest problem.

Wheat bulk is generally the cheapest and most used winter cover crop. We plant wheat bulk in November, with an application rate of 2.5 bushels/ac (6.25 bushels/ha) and harrowed in lightly with a drag on the back of the harrow. No water, fertilizer, or herbicide are applied.

This past year, we waited for the wheat to mature and dry, and then drilled sudan grass right on top of it, disturbing the soil as little as possible. This worked very well because sudan grass seeds were already germinating from the application of sudan grass during the previous summer. The rate of application is around 30 lb/ac (34 kg/ha). Sudan grass, as well as wheat, rye, and millet, seem to be nonhosts of needle nematodes (*Longidorus* spp.) (Cram and Fraedrich, this proceedings).

Nutsedge control is a big factor to consider. The nursery routinely sprayed all fallow fields 2 or 3 times each summer in the past in an attempt to eradicate nutsedge. The nursery is now trying to keep fields in some type of cover crop when not in seedling production.

Costs Involved for Cover Crops

No costs are involved for rye sown at Walker Nursery. All costs are incurred by the DOC.

Costs at Flint River Nursery usually range from U.S. $7 to $10 per bushel for wheat bagged, and U.S. $4 to $6 per bushel bulk. Sudan grass ranges from U.S. $9 to $13 per 50 lb (23 kg) bag. Sorghum sudan is the most beneficial and costs less per acre overall.

With the uncertainty of methyl bromide in the future, it is more important than ever to include cover crops in our regime. In the first year for non-fumigated hardwoods, the weed control from residual seeds left behind is the only problem. This is never a problem in first-year fumigated hardwoods or pines where broad spectrum herbicides can be used.

Weed Control in Bareroot Hardwood Nurseries

David B. South
William A. Carey

David B. South is Professor, School of Forestry and Wildlife Sciences, Auburn University, AL 36849-5418; telephone: 334.844.1022; e-mail: southdb@auburn.edu. William A. Carey, deceased, was Research Fellow, School of Forestry and Wildlife Sciences, Auburn University, AL.

In: Dumroese, R. K.; Riley, L. E.; Landis, T. D., tech. coords. 2005. National proceedings: Forest and Conservation Nursery Associations—2004; 2004 July 12–15; Charleston, NC; and 2004 July 26–29; Medford, OR. Proc. RMRS-P-35. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Abstract: Managers in the southern United States rely on chemical and non-chemical methods of weed control. Chemical treatments include fumigation with methyl bromide and chloropicrin in combination with selective herbicides. If methyl bromide is no longer produced in the future, the amount of handweeding will likely increase unless managers adapt to the change. Some nursery managers will increase use of both sanitation practices and herbicides. Although several herbicides are registered for use on hardwoods, some formulations can injure seedlings if applied to seedbeds. Grasses can be effectively controlled with selective herbicides and many small-seeded broadleaf weeds can be suppressed with preemergence herbicides. Several nursery managers have fabricated shielded herbicide sprayers to apply herbicides between drills.

Keywords: herbicides, fumigation, integrated pest management

Introduction

Hardwoods grown in southern forest nurseries represent approximately 4% of the total seedling production. Less than half of the forest tree nurseries in the South grow hardwoods. In 2002, total production from hardwood nurseries was less than 50 million seedlings (McNabb and VanderSchaaf 2003). However, on an area basis, a hardwood crop is more valuable than a pine (*Pinus* spp.) crop. One hectare (2.5 ac) of hardwoods typically produces about 440,000 seedlings (each worth about U.S. $0.30 each). This amounts to a crop value of over U.S. $130,000/ha (U.S. $52,000/ac).

Oaks (*Quercus* spp.) account for more than half of the hardwood production (Table 1). Other large-seeded species include hickory (*Carya* spp.), pecan (*Carya illionensis* [Wangenh.] Sarg.), and black walnut (*Juglans nigra* L.). Small-seeded species include yellow poplar (*Liriodendron tulipifera* L.), green ash (*Fraxinus pennsylvanica* Marsh.), cottonwood (*Populus deltoides* Bartr.), sycamore (*Platanus occidentalis* L.), sweetgum (*Liquidambar styraciflua* L.), and dogwood (*Cornus florida* L.).

Developing herbicide programs for individual species such as black walnut can be difficult because relatively few seedlings are produced. Due to the high crop value of hardwoods, several managers prefer that herbicide screening tests be limited to pines. For these reasons, weed control research in hardwood seedbeds has concentrated on developing herbicide programs that are suitable for most hardwoods. Without herbicides, handweeding in hardwood seedbed might exceed 500 hr/ha (200 hr/ac). Although a nursery may grow only a few hectares of hardwoods each year, handweeding times might exceed that for a much larger area of conifers. For example, untreated hardwood seedbeds at one nursery required more than 3,900 hr/ha (1,560 hr/ac) of handweeding (Abrahamson 1987). When combining soil fumigation with herbicides, hardwood seedbeds now require only 60 to 250 hr/ha (24 to 100 hr/ac) of handweeding.

Management Practices

Efficient weed management systems for hardwoods involve a combination of methods which may include sanitation, living mulch, fumigation, and herbicides. Less efficient systems usually rely on just 1 or 2 methods of weed management.

Table 1—Hardwood seedling production from nurseries in 2002 (McNabb and VanderSchaaf 2003).

Group	Bareroot	Container	Total
Oaks	27,325,800	171,100	27,496,900
Green ash	2,621,500	7,000	2,628,500
Yellow poplar	1,282,800	14,000	1,296,800
Dogwood	892,900	8,000	900,900
Pecan	892,000	0	892,000
Sycamore	782,000	7,000	789,000
Sweetgum	638,200	3,000	342,200
Black walnut	508,000	0	508,000
Cottonwood	320,000	0	320,000
Others	11,849,000	33,400	11,882,400
Total	47,112,200	243,500	47,355,700

Sanitation

Sanitation is an important component of an effective weed control program (Wichman 1982). For this reason, it is important to prevent the introduction of weed seeds in composts, mulches, seeds, and irrigation water. Composts were used in the past to increase soil fertility, but they were a source of weed seeds. Adding leaves from lawns or municipal sludge to the soil can also introduce weeds. Therefore, composts are typically not used in hardwood seedbeds.

Weed seeds can be present in mulches such as pine straw, wheat straw and, in some situations, sawdust. During the 1950s, pine straw was the favored mulch at many hardwood nurseries, but it often introduced a significant amount of grass seeds (South 1976). Today, several hardwood managers use weed-free, polyethylene soil stabilizers instead of straw mulches.

Several nursery managers use certified seeds for cover-crops to reduce the introduction of noxious weeds. Regulations require certified seeds to be free of primary noxious weed seeds and only small amounts of common weed seeds are allowed. Several managers sow cover-crops at densities that keep soil shaded to suppress weed growth. In particular, nutsedge (*Cyperus* spp.) competes poorly when shaded by dense cover crops.

Irrigation water can be a major source of weed seeds, especially when pumped from lakes, ponds, or rivers. For this reason, several nurseries use in-line screens to filter weed seeds. Some of the newer filter systems are self-cleaning.

Weed seeds, rhizomes, and tubers are easily introduced to a nursery on farm equipment that is rented or borrowed from adjacent landowners. For this reason, some managers thoroughly clean rented combines before harvesting cover crops. Some managers avoid this potential weed source by not harvesting corn (*Zea mays* L.).

Mechanical Cultivation

Since the drill spacing within a seedbed is often 30 to 60 cm (12 to 24 in), mechanical cultivation is more feasible than in most pine seedbeds (South 1988). At one nursery, mechanical cultivation reduced handweeding requirements by 21 hr/ha (8.5 hr/ac) (Barham 1980). Although reductions in weed densities can be achieved by mechanical cultivation (South 1988), most hardwood nurseries in the South rely on other weed-control practices.

Living Mulch

The concept of a "living mulch" was introduced into the South by the Virginia Department of Forestry during the 1980s. Rye (*Secale cereale* L.) seeds were drilled into the sections immediately before sowing white pine (*Pinus strobus* L.) and hardwoods in the fall. The "living mulch" protected the fall sown seedbeds from injury by wind, rain, and frost. This system was also effective for fall-sown hardwoods in Illinois and Indiana (Stauder 1993; Wichman 1993). Nursery managers in Georgia and Tennessee currently use this system on fall-sown hardwoods (Ensminger 2002). Wheat (*Triticum aestivum* L.), rye, or oats (*Avena sativa* L.) is sown on prepared beds before fall sowing acorns. The grass mulch is sprayed with glyphosate in February prior to emergence of oak seedlings. This system provides several advantages, including a retardation of weed growth.

Fumigation

It is relatively easy to justify soil fumigation, which typically costs less than 2% of the value of the hardwood crop. For this reason, most hardwood managers in the South fumigate the soil prior to each hardwood seedling crop. Although dazomet is used in northern hardwood nurseries (Schroeder and Alspach 1995; Storandt 2002), hardwood managers in the South have relied on methyl bromide/chloropicrin fumigation to reduce pest populations. One advantage of methyl bromide/chloropicrin is that it can be used relatively close to fields containing seedlings. In some situations, injury to adjacent crops has occurred when dazomet or metham sodium was applied without a tarp (Scholtes 1989; Buzzo 2003).

Few hardwood nurseries have problems growing endomycorrhizal crops after fumigating with 98% methyl bromide (Campbell 1992). So far, fumigation tests with 336 kg/ha (300 lb/ac) of chloropicrin have not detrimentally affected sweetgum or oaks. Methyl bromide fumigation that included chloropicrin at 129 to 168 kg/ha (115 to 150 lb/ac) has occasionally reduced growth of some species (for example, sweetgum and dogwood). This was due to a deficiency of endomycorrhizal inoculum (South and others 1980). In fact, in 1994, one nursery in Georgia had stunted corn due to effective fumigation with 33% chloropicrin and 66% methyl bromide. Some managers may use other fumigants such as dazomet or 1,3-dichloropropene for beds to be sown with dogwood or sweetgum.

In the future, methyl bromide will continue to be produced by oceans, fires, plants, and fungi. However, it is possible that in the future, it will no longer be used as a fumigant due to restrictions on production. If this turns out to be true, some managers will likely switch to fumigants that are relatively weak on weeds. Possible alternatives include chloropicrin and dazomet. Although both can control certain soil-borne pests, neither is as effective in controlling nutsedge as methyl bromide (Carey 1995; Carey and South 1999; Fraedrich and Dwinell 2003).

Herbicides

To control weeds without injuring hardwood seedlings, the herbicide must either be selective (such as fluziflop-butyl; see Table 2 for common names) or it must be applied in a manner that avoids seedling injury. Selectivity is based on physiological or morphological differences between crop and weed. For example, a physiological difference between broadleaves and grasses is the basis of selectivity for sethoxydim and for fluziflop-butyl. As a result, handweeding grasses should no longer be necessary. Many annual broadleaf weeds can be controlled with other herbicides (South and Gjerstad 1980; South 1984, 1992; Porterfield and others 1993; Altland and others 2003).

Morphological differences between crop seeds and weed seeds can be used to provide some selectivity. Large-seeded species such as oak, walnut, pecan, and hickory tolerate preemergence herbicides that might kill small-seeded species. For example, oxyfluorfen can be applied after sowing without injury to walnut, pecan, hickory, and oak.

Differences in plant size can also influence selectivity. Some herbicides (like trifluralin, oryzalin, prodiamine, and napropamide) are active mainly on seed germination. These herbicides can be applied once hardwood seedlings have germinated and have developed a few true leaves. The herbicides can be toxic to small hardwood seeds, such as sycamore, if applied at time of sowing. When applied after the seedlings are established, the chance of injury is greatly reduced. Although these herbicides do not control emerged weeds, they will help keep subsequent weed seeds from germinating. This technique is used successfully by several nursery managers in the South.

With some herbicides, formulation affects selectivity. Formulating herbicides as granules is a common practice to reduce injury. When applied to dry foliage, herbicide granules of oxyfluorfen and oxadiazon are less phytotoxic than liquid formulations. Herbicide injury still occurs if granules lodge in the foliage or are not completely washed off with irrigation. Therefore, it is important for most granules to be applied to dry foliage. At some nurseries, irrigation is applied immediately after treatment to increase selectivity.

Although granular herbicides are commonly used in container nurseries that produce horticultural plants (Everest and others 1998), bareroot nurseries rarely use granular herbicides. Although effective weed control can be obtained with granular herbicides (Reeder and others 1992), many managers apply cheaper liquid formulations as broadcast sprays. For example, 1 kg (2.2 lb) of napropamide might cost U.S. $13 as a powder and U.S. $100 as a granular formulation. A partial list of trade names of granular herbicides used in ornamental container nurseries is provided in Table 2.

Selectivity can be increased by avoiding contact to crop foliage. This can be done with either using hand-held equipment or by using shields to apply herbicides between drill rows (Figure 1). Most foliar active herbicides should be directed away from the crop and toward the weeds. A number of nursery managers have fabricated equipment to apply glyphosate to weeds between seedling drills (see Stallard, this proceedings; Vachowski, this proceedings).

A final way to provide selectivity is to apply the herbicide to the cover-crop instead of treating the hardwood crop directly. For example, some nursery managers sow Roundup Ready® corn and then spray glyphosate to kill nutsedge and troublesome annual weeds. There are several new herbicides that are registered for use on cover crops (Webster 2003) but are not legal for use on hardwood seedbeds.

Table 2—Common names, trade names, and manufacturers of selected herbicides.

Trade name	Common name	Company
Selective grass herbicides		
Acclaim®	Fenoxaprop-ethyl	Bayer
Fusilade® II	Fluazifop-butyl	Syngenta
Vantage®	Sethoxydim	BASF
Envoy®	Clethodim	Valent
Selective herbicides		
Barricade®	Prodiamine	Syngenta
Dacthal®	DCPA	Amvac
Devrinol®	Napropamide	United Phosphorus
Treflan™ 4EC	Trifluralin	Monterey
Pennant® Magnum™	Metoalochlor	Syngenta
Granules		
BroadStar™	Flumioxazin	Valent
Devrinol® 2G	Napropamide	United Phosphorus
Ronstar® G	Oxidiazon	Bayer
Rout®	Oxyfluorfen+oryzalin	Scotts
OH2®	Oxyfluorfen+pendimethalin	Scotts
Regal O-O®	Oxyfluorfen+oxadiazon	Regal
Pendulum®	Pendimethalin	BASF
Non-selective		
Basagran® T/O	Bentazon	BASF
Finale®	Glufosinate-ammonium	Bayer
Roundup Pro®	Glyphosate	Monsanto

Figure 1—A directed herbicide sprayer for hardwood seedlings at the East Tennessee Nursery.

Treatments Used by Managers

Commonly used herbicides were determined by surveying 14 hardwood nurseries. Methyl bromide/chloropicrin fumigation was used at all of the nurseries. To suppress hardwood diseases and to reduce the consumption of methyl bromide, several managers used methyl bromide with 33% chloropicrin.

Half of the nursery managers (7) used no herbicides at time of sowing. Some were afraid that herbicides could result in seedling injury. Five nurseries had good results in tests of oxyfluorfen on large-seeded species such as oaks, persimmons (*Diospyros virginiana*), and hickories. One nursery applied EPTC as a pre-sow, soil-incorporated treatment. Trifluralin was used after sowing at 2 nurseries.

Managers at 13 nurseries used postemergence herbicides (applied postemergence to the crop). Selective grass herbicides were the most popular. Sethoxydim was used at 8 nurseries and 7 nurseries used fluzifop-butyl. One nursery applied the granular herbicide Rout® to a limited amount of emerged seedlings.

Napropamide was applied postemergence to the crop at 6 nurseries and prodiamine was applied in a like manner at 4 nurseries. These herbicides can be applied to seedbeds after germination of hardwoods is complete (South 1984, 1992). These herbicides do not have contact activity and therefore are not generally phytotoxic to emerged seedlings or weeds (Skroch 1994; Everest and others 1998).

Glyphosate was used as a directed spray (Figure 1) at 5 nurseries as needed to weeds that were tolerant of other herbicides. Several nurseries have constructed shielded applicators to apply glyphosate between seedling drills.

Managers at 6 nurseries apply a soil stabilizer after sowing hardwoods. Rates vary depending on season, soils, rainfall patterns, and budgets. One manager applies 1,122 l/ha (118 gal/ac) of Agrilock® over fall-sown beds (over sawdust mulch) while 561 l/ha (59 gal/ac) are applied after sowing in the spring (with no sawdust mulch). Two managers used rates as low as 330 l/ha (35 gal/ac).

Comments by Managers

The following edited comments are from 9 nursery managers:

1. Cover small seeds with mulch or soil at the time of sowing (especially when treating with a soil stabilizer).
2. Trifluralin (applied just after sowing) caused some damage to sycamore.
3. No problems were encountered with sethoxydim or trifluralin. Oryzalin slightly damaged dogwood, sycamore, sweetgum, and maple (*Acer* spp.). OH-2® injured deciduous magnolias (*Magnolia* spp.), maples, dogwood, and sweetgum.
4. Soil-incorporated EPTC, applied 30 days before sowing in the spring, does not seem to have any effect on seedlings. We also have treated soil in fall before sowing in spring.
5. Oxyfluorfen applied as a postemergence herbicide to oaks, and watered in immediately, causes some slight burning, but does not have any long lasting effect on the seedlings.
6. Pendimethalin at sowing gives good control in oaks and pecan.
7. Metolachlor applied as a preemergence herbicide (after sowing) slows the germination of white oak and sawtooth oak, but has little noticeable effect in water, willow, cherrybark, Nuttall, or Shumard oaks.
8. Metolachlor applied as a postemergence herbicide to hardwoods slows the growth of seedlings a little, but not adversely so.
9. Oxyfluorfen can be used on large-seeded oaks, persimmons, and hickories. A surfactant rather than oil should be used when using sethoxydim or fluziflop-butyl. Using a crop-oil can damage hardwoods. Shrub lespedeza (*Lespedeza thunbergii* (DC.) Nakai) can be treated with 2,4-D amine.
10. Sethoxydim should be applied before (not after) top-pruning oaks.

Conclusion

Due to the numerous species involved, a single herbicide regime is unlikely to be effective for all hardwood species. South (1995) proposed a regime that could be adapted for a variety of hardwood species. A regime of this type should be used in conjunction with a rigorous sanitation program. The regime relies on use of a selective grass herbicide (for example, fenoxaprop-ethyl, fluazifop-butyl, sethoxydim) in conjunction with a few other herbicides (napropamide, prodiamine, oryzalin) to control germination of small-seeded broadleaf weeds. Oxyfluorfen can be used for large-seeded field-grown ornamentals. Nutsedge is controlled with glyphosate on fallow land (South 1979; Fraedrich and others 2003) while emerged weeds are controlled with either handweeding or directed applications of glyphosate or glufosinate-ammonium. Due primarily to a difference in herbicide use, some claim that weed control in bareroot seedbeds is now easier than controlling weeds in container nurseries (McRae 1999).

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Panel Discussion: Weed Management

Don Stringfield

Don Stringfield is Nursery Superintendent at MeadWestvaco Forest Tree Nursery, 6803 Hyde Park Road, Ravenel, SC 29470; telephone: 843.556.8391; e-mail: das17@meadwestvaco.com

In: Dumroese, R. K.; Riley, L. E.; Landis, T. D., tech. coords. 2005. National proceedings: Forest and Conservation Nursery Associations—2004; 2004 July 12–15; Charleston, NC; and 2004 July 26–29; Medford, OR. Proc. RMRS-P-35. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Abstract: Successful weed management must be an incorporation of techniques and ideas. Habitual practices of cleaning equipment, using the proper cover crop, spraying small amounts of herbicides early and more often, timing of applications, and the use of the correct mulch/resin are all important lines of attack in keeping the nursery free of competing vegetation. The methods presented are methods used at MeadWestvaco's forest tree nursery in Ravenel, SC.

Keywords: bareroot seedlings, fumigation, methyl bromide, herbicides

Introduction

Weed management has advanced greatly in the last 20 years, particularly as it relates to pines. Weed eradication in hardwoods can still be a very challenging effort. The potential of a "weedy crop," even in pines, is very much possible when coupled with a lackadaisical attitude about weed management.

Different nurseries have different weed species and different means of handling their problems. It is common knowledge that what works for one situation may not work for another. The methods I have listed work in our nursery.

Methods

Fumigation and Herbicides

Pines—Methyl bromide is applied at a rate of 400 lb/ac (448 kg/ha) and 2 crops of pine are grown on that particular field. We use a pre-emergence application of Goal™ 2XL (oxyflourfen) at 58 oz/ac (4.25 l/ha). Then approximately 35 to 40 days after sowing, we start post-emergence applications of Goal™ at 9.6 oz/ac (0.7 l/ha) plus 6 oz/ac (0.4 l/ha) of non-ionic adjuvant (Agridex®). The post-emergence application is applied every week for 3 to 4 weeks, then every other week for 3 to 4 weeks. The limit on Goal™ is 1 gal/ac (57 l/ha) per year.

Weekly and bi-weekly applications of Goal™ are more effective than monthly applications for 2 reasons. The first involves better timing of the post-emergence sprays with the stage of weed development. With weekly or bi-weekly applications, emerged weeds are small. In general, small weeds have not developed enough wax on the leaf surfaces to protect against contact herbicides like Goal™. The second reason involves replacing the chemical barrier to germinating weeds. When applied to the soil surface, Goal™ acts as a pre-emergence herbicide and kills weeds as they emerge through the chemical barrier. When the barrier is broken (due to heavy rains, irrigation, tractor tires, or hand weeding) weeds can emerge in the herbicide-free "cracks." With weekly and bi-weekly applications, the holes in the chemical barrier are replaced with a new layer of herbicide.

Another herbicide that is very good on grasses is Poast® (sethoxydim) used at 24 oz/ac (1.8 l/ha) mixed with 24 oz/ac (1.8 l/ha) of Agridex® (non-ionic adjuvant). If Poast® is used early (within 6 weeks of sowing) the adjuvant is cut to half rate (12 oz/ac [0.6 l/ha]).

Hardwoods—Hardwood fields receive methyl bromide at a rate of 275 lb/ac (308 kg/ha), rather than 400 lb/ac (448 kg/ha), and only 1 crop is grown on that particular fumigation. We have found that rates exceeding 300 lb/ac (336 kg/ha) on our soils have a negative impact on the endomycorrhizae that many hardwoods depend upon. We don't receive the full potential of weed control with this reduced dosage, but we generally raise a uniform seedling crop.

We use Trifluralin as a pre-emergence at the rate of 1 qt/ac (2.4 l/ha) on all hardwoods except sycamore. Devrinol® 50DF is used several times during the growing season at 4 lb product/ac (4.5 kg product/ha). Poast® is used at the same rate as that for pine. Generally 4+ hand weedings are necessary. This is more than for pine.

Cover Crop

We have tried several cover crops over the years. Since our sandy soils require more organic matter than any green manure crop can give us, we add our organic matter as fresh sawdust and plant a cover crop of Abruzzi rye (*Secale cereale* var. *abrusses*). Rye is planted in the fall (October); it has no competition from weeds at that time, thus no herbicides are needed. We let it grow until the next August or early September, then disk it in. We plant it again in October, or treat the field with methyl bromide if it is scheduled for a seedling crop.

Abruzzi rye, when planted at 2.5 to 3.0 bushels/ac (6.3 to 7.5 bushels/ha) forms a dense 6 to 8 ft (2 to 2.4 m) tall crop that shades out competing vegetation all spring and summer. We add 20 tons/ac (50 tons/ha) of fresh sawdust on approximately 40 ac (16 ha) of land per year. As I said earlier, green manure crops, even at 2 per year, will not keep us in the range of organic matter we desire. Abruzzi rye fits our needs, our pocketbooks, and is low maintenance.

Mulches

Pines—We only use Agrilock®, a co-polymer resin. This has greatly reduced the introduction of weed seeds as compared to mulches used in the past.

Hardwoods—All fall-sown hardwood seeds are covered with fresh sawdust (weedless), and then sprayed with Agrilock®. Spring-sown hardwood seeds only receive the resin, no sawdust. Sawdust applied in the fall keeps the top of the seedling bed pliable. If sawdust is not applied, the bed will form a hard crust over winter, making seed emergence difficult, particularly on small-seeded species.

We fall sow as many species of hardwoods as possible. Early spring growth means early canopy closure, which equals less weeds.

Irrigation Lines

Irrigation lines are sprayed the same time the seeding beds are sprayed, with whatever herbicide is being applied.

Fallow Areas/Roadsides/Ditch Banks

Fallow areas that stay fallow long enough to produce weeds will be treated with Roundup™ or its generic form at the labeled rate. Roadsides, field edges, and ditch banks are sprayed with Roundup™ several times during the spring and summer.

Equipment

Before a disk, turn-plow, chisel-plow, subsoiler, or drag-harrow is moved from one field to another, it travels to the wash rack and is steam cleaned. This is particularly helpful in controlling nutsedge movement.

Summary

Preventing the introduction, reproduction, and spreading of weeds, coupled with correct herbicides, proper rate, and time of application, all go hand-in-hand as a mechanism to control weeds year-round.

Panel Discussion: Weed Control Practices in Seedbeds of Deciduous Trees and Shrubs in the Indiana Department of Natural Resources Nursery Program

Jim Wichman

Jim Wichman is Nursery Program Supervisor for the Indiana Department of Natural Resources, Vallonia Nursery, 2782 W County Road 540 S, Vallonia, IN 47281; telephone: 812.358.3621; e-mail: jwichman@dnr.in.gov

In: Dumroese, R. K.; Riley, L. E.; Landis, T. D., tech. coords. 2005. National proceedings: Forest and Conservation Nursery Associations—2004; 2004 July 12–15; Charleston, NC; and 2004 July 26–29; Medford, OR. Proc. RMRS-P-35. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Abstract: A summary of weed control practices used in seedbeds of deciduous species at Indiana Department of Natural Resources nurseries is presented.

Keywords: bareroot seedlings, fumigation, herbicides, hand weeding

Seedling Production Statistics

During the 2003 and 2004 growing season, seedling production at Indiana Department of Natural Resources (IDNR) nurseries included the following: 6 species of conifers, totaling 942,317 seedlings; 18 species of shrubs, totaling 612,821 seedlings; 29 species of deciduous trees, totaling 4,297,620 seedlings.

Weed Control Practices

Sanitation

Fumigation and herbicides kill a large percentage of weeds or weed seeds, but not 100%. Reducing weed seed levels is critical, as 1% of 10,000 are manageable, but 1% of 1,000,000 may not be manageable.

Weeds from maturing seeds in the seedbeds can be prevented by applying appropriate herbicides and hand weeding. Weeds from maturing seeds in the cover crop rotation can be prevented by the following: (1) sowing corn and sorghum green manure crops at high density; (2) applying herbicides in cover crops; (3) planting Roundup Ready® corn or Concept-treated sorghum; (4) applying Harmony® Extra in small grains; (5) preventing weeds from maturing seeds in areas adjacent to the seedbeds by applying appropriate herbicides to control species that have wind-blown seeds or seeds easily tracked into seedbeds; (6) maintaining dense stands of fescue or other cover crops in waterways and bedends.

Fumigation

Methyl bromide is applied at 300 lb/ac (336 kg/ha) at IDNR nurseries for both disease and weed control.

Use of Herbicides in Seedbeds

Glyphosate and Paraquat—Roundup™ or Gramoxone® is applied as a preemergence herbicide to seedlings in all seedbeds to kill established weeds and the cover crop planted with tree seeds.

Simazine—Princep® Caliper 90® (Special Local Needs Registration) is applied both as a pre- and postemergence herbicide to seedlings with residual activity on many grass and broadleaf weeds. It is applied to all large-seeded 1+0 and 2+0 deciduous species. The herbicide has some postemergence activity on small-emerged weeds of susceptible species.

Prodiamine—Endurance® or Barricade® is applied as a postemergence herbicide to seedlings, with residual activity for many grass and broadleaf weeds. This treatment is applied to all 1+0 and 2+0 deciduous species. They are the only soil active herbicides used on small-seeded deciduous species. These herbicides can suppress the corn cover crop in the following season.

Oxyfluorfen—Goal™ is applied as a postemergence herbicide to 1+0 for 2+0 seedlings. It is applied to 2+0 oaks and hickories before seedlings break dormancy. Goal™ has both pre- and postemergence activity on many, but not all, weeds.

Fluazifop-butyl—Fusilade® is applied as a post-emergence herbicide to all species and age-classes to control grass species.

Fire

Fire can be used prior to seedling emergence. It can be used to remove straw from all straw mulched seedbeds and to kill most established weeds and weed seeds in the straw. It does not completely kill wheat or rye cover crops.

Hand Weeding

Hand weeding is expensive, but is necessary to some degree every year. The Indiana Department of Corrections (IDOC) offenders earn U.S. $0.90/day. IDNR intermittent laborers earn U.S. $8.99/hour. Expenditures for hand-weeding in 2003 were approximately U.S. $0.005/seedling or U.S. $750/ac (U.S $1,875/ha).

National Wild Turkey Federation Programs

Rob Keck

Rob Keck is Chief Executive Officer of the National Wild Turkey Federation, PO Box 530, Edgefield, SC 29824; telephone: 803.637.3106; e-mail: nwtf@nwtf.net

In: Dumroese, R. K.; Riley, L. E.; Landis, T. D., tech. coords. 2005. National proceedings: Forest and Conservation Nursery Associations—2004; 2004 July 12–15; Charleston, NC; and 2004 July 26–29; Medford, OR. Proc. RMRS-P-35. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Keywords—wildlife conservation, forest management, American chestnut, Operation Oak

Introduction

I recently read an article about several women who were preparing to sit 80 ft (25 m) above a forest floor in tree-sitting nets to protest a logging operation in Jefferson National Forest (Appalachia). Tree hugging is nothing new in this country. But did environmental activists know we have more forests now than we did in the 1920s? In 1920, we only had 735 million ac (297 million ha) of forest land. Today we have 749 million ac (303 million ha), or 2 ac (0.8 ha) for every single person in America thanks to you and others in the nursery industry.

Advances in forestry management have had great benefits for people and wildlife. Habitat is critical for good wild turkey populations. And trees, specifically oak trees, are an important component. The mission statement of the National Wild Turkey Federation (NWTF) makes it clear we're committed to the conservation of the wild turkey and the preservation of our hunting heritage. Habitat improvement is a big part of what we do.

Together, the NWTF and its conservation partners have spent more than U.S. $186 million in the Wild Turkey Super Fund on over 27,000 projects to support that mission throughout North America. And we have made a difference. When the National Wild Turkey Federation was founded in 1973, there were only 1.3 million wild turkeys in North America. Today, that number has increased to more than 6.4 million birds thanks to State, Federal, and provincial wildlife agencies, and our members and partners. Our restoration efforts would not have been as successful if we hadn't worked to improve habitat.

Our nearly 525,000 members and 2,100 chapters, which are located in every State in the country as well as Canada, are passionate about making a difference on the ground. This country's sportsmen and women—hunters—have a long history of putting their money, their time, and their hearts and souls into restoring this country's wildlife and managing the land. Hunters contribute U.S. $4.7 million every day, adding up to U.S. $1.7 billion every year for conservation. And through this country's private groups such as the Federation, sportsmen contribute another U.S. $300 million each year.

It's those dollars that fund wildlife management, hunter education, and research. And it's a big reason for the return of the wild turkey, whitetails, black bears, Canada geese, pronghorns, river otters, and even our nation's symbol, the bald eagle. Target shooters and hunters have been and will continue to be the most important factor in wildlife conservation this country has ever known. This country's sportsmen are connected to the land because they've dug into the earth with their hands, planted trees, created openings, and more. Their work benefits far more than wild turkeys. Many other wildlife species, including songbirds, profit as well. Because of that, we take land management pretty seriously at the Federation.

Our approach to land management occurs on many levels and in many different ways, from offering low-cost seeds and seedlings, to the expertise of our staff, and more. We have 10 regional biologists in the field and 13 biologists at headquarters who are working to improve habitat on public, private, and corporate lands.

In addition to the state-of-the-art museum at our national headquarters in Edgefield, South Carolina, we have a beautiful Outdoor Education Center. At this 100-ac (40-ha) Outdoor Education Center, we can show visitors first hand what good habitat management looks like. Our Web site, 5 national magazines, and national television shows are filled with tips and advice for improving wildlife habitat. Our new show, *Get in the Game*, is dedicated to land management. We got the message loud and clear about how interested people are in managing their lands. We did a survey last year on the economics of turkey hunting, and we found something that surprised us. While you might think turkey hunters spent most of their money on guns or trucks or hunting gear, their biggest expenditure is actually for habitat improvements, at over U.S. $240 million per year. On average, turkey hunters spend U.S. $105 per year on improving habitat. Hunters in the Southern region spent the most on habitat improvement at over U.S. $170 per year.

NWTF Programs and Seedlings Planted

We've made some big strides in being able to offer quality seedlings thanks to some great partnerships. For over 5 years, we have been working with State forestry commissions in Georgia, Texas, Mississippi, and South Carolina to improve the size and quality of the oak trees produced. This year, we are growing 50,000 trees in South Carolina for planting in Iowa and 40,000 trees in Georgia for Mississippi and Georgia. These select trees produce acorns in 7 to 9 years that can provide the food and habitat wild turkeys need. Through regional habitat programs, we plant seedlings from coast to coast.

Operations

Operation Oak—Under this program, 60,000 sawtooth oaks (*Quercus acutissima*) with tree survival kits have been produced and shipped over the past 5 years. This year, 8,000 select white oaks (*Q. alba*) were provided by the South Carolina Forestry Commission. The NWTF is expanding its Operation Oak program to include more States and plant more seedlings. We plan to plant over 300,000 high quality oak seedlings during the next 3 years throughout the Southeast and Midwest.

Operation Heartland—This program has provided 300,000 oaks (white, southern red [*Q. falcata*], bur [*Q. macrocarpa*], and pin [*Q. palustris*]), and mast-producing shrubs (crabapple [*Malus* spp.]).

Operation Appleseed—Over—50,000 crabapples with tree survival kits have been planted during this program.

Operation SOS—Approximately 600,000 northern red oak (*Q. rubra*), cranberry (*Vaccinium* spp.), crabapple, and hawthorn (*Crataegus* spp.) have been produced for this operation.

Michigan Winter Habitat Project—Approximately 50,000 crabapples with tree survival kits have been produced for this project.

Operation Big Sky—This operation has provided 200,000 assorted mast-producing seedlings for outplanting.

Guzzlers for Gobblers—Approximately 100,000 cottonwood and assorted mast-producing seedlings have been produced and outplanted.

The Scoop on Our Seedlings

We've planted seedlings in every State (except Alaska), and in Ontario and Manitoba. All are bareroot seedlings (white, red, pin, and bur oaks, cranberry, crabapple, hawthorn). The NWTF strives to provide the highest quality seedlings available. We prefer seedlings that are 24 to 36 in (60 to 90 cm) in height with good lateral roots.

The following organizations, companies, and partners are involved in the implementation of the various seedling programs: USDA Forest Service, South Carolina Forestry Commission, Georgia Forestry Commission, University of Georgia, Iowa Forestry Commission, Texas Forestry Commission, MeadWestvaco Company, International Paper Company, Lee Nursery, Musser Farms, and NWTF volunteers.

Programs Geared to the Private Landowner

Much of this country's forests are owned by individual landowners. In fact, these landowners account for 220 million ac (89 million ha). Individual property owners have typically owned the land for less than 15 years and don't actively manage their forests. The success of managing forests for wildlife depends on our ability to market forest management to these folks. Recognizing that, the Federation has developed several programs designed to help the individual landowner.

Wild Turkey Woodlands is the Federation's program that encourages management on private lands. Through this program, we recognize landowners for the good wildlife work they are doing. In addition, landowners get the latest information about wild turkey management.

Project HELP® (Habitat Enhancement Land Program) is a Federation program developed to help landowners manage their land by providing guidance and offering seeds and seedlings at competitive prices.

We offer lots of information in the form of videos, manuals, bulletins, CDs, and more.

Research to Save the American Chestnut

Since 1977, the NWTF has provided U.S. $3.4 million in national project research grants to many State agencies and universities. While these grants fund different projects, they all share the common goal of "Working for the wild turkey." We're currently funding a project to develop chestnut trees (*Castanea dentata*) that are resistant to blight.

Prior to the 20th century, chestnuts were a major food source in the Appalachian Mountains. Today, few remain. To bring the chestnuts back, the USDA Forest Service, the American Chestnut Cooperators' Foundation, Virginia Polytechnic Institute, and the NWTF are combining their research and resources to fight the blight in the Jefferson National Forest in Virginia. These organizations are working to breed blight-resistant chestnut trees. They inoculate these trees with a weak strain of the blight that contains a virus that attacks the nastier wild strain. They cut away parts of the most successful trees and graft them onto root systems of trees that have already gotten the disease. This grafting allows healthy, blight-resistant sprouts to use already established root systems to grow more quickly into nut-producing chestnuts. The NWTF helped support the Chestnut Foundation's research and helped locate good potential chestnut habitat in the Jefferson National Forest. Because of these efforts, the American chestnut may once again become an established food source for wildlife.

While groups such as Save America's Forests are waving chainsaws at the White House warning that loss of forests is at a crisis level in this country, we're really enjoying the "good old days" of forestry. We have genetic improvements and new techniques that will help us produce healthier trees faster than ever before. While we do cut lots of timber, you help us make sure we grow more than we cut.

As we look to the future, it will be our responsibility to balance people's need for forest products with the needs of wildlife. There are a great many people out there who don't understand that active management of our forests is good. They are convinced that any tree removal is cause for heading for the nearest tree-sitting net. They want to set aside land that nobody can use and prevent us from using our renewable natural resources.

I'm sure we all recognize the need to conserve old forests. However, young forest habitats created today, almost solely through forest management practices, are important to many species of wildlife—from whitetails to warblers. The Federation endorses a balanced approach to forest management. We realize commercial forest management is far more than harvesting trees. It's an important tool that allows us to improve wildlife habitat. No single forest, young or old, pine or hardwood, can provide suitable habitat for all forest wildlife. Ideally, we want a diverse forest landscape, supporting young and old stands of all native forest types to sustain wildlife populations.

By using a common sense approach to management, we'll be leaving our forests in better shape than we found them, for our children and beyond.

For more information on the Wild Turkey Super Fund, contact:

Tammy Sapp, VP of Communications
National Wild Turkey Federation
Office phone: 803.637.3106
Cell phone: 803.480.1841
E-mail: tsapp@nwtf.net

Visit www.nwtf.org today—your source for all things wild turkey!

Management Options for Control of a Stunt and Needle Nematode in Southern Forest Nurseries

Michelle M. Cram
Stephen W. Fraedrich

Michelle M. Cram is Plant Pathologist, Forest Health Protection, USDA Forest Service, Athens, GA 30602-2044; telephone: 706.559.4233; e-mail: mcram@fs.fed.us. Stephen W. Fraedrich is Research Pathologist, Southern Research Station, USDA Forest Service, Athens, GA 30602-2044; telephone: 706.559.4273; e-mail: sfraedrich@fs.fed.us

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Abstract: Crop rotation and fallow are management options that can be used to control plant parasitic nematodes in forest tree nurseries. Before these options can be put into practice, it is important to determine the host range and survivability under fallow of the parasitic nematode to be controlled. The results of host range tests on a needle nematode (*Longidorus* spp.) and a stunt nematode (*Tylenchorhynchus ewingi*) indicate that crop rotation practices were a factor leading up to the development of damage by these nematodes at 2 Southern nurseries. The needle nematode became a problem in a field following crop rotations of loblolly pine with white oak. The host range of the needle nematode was found to include white (*Quercus alba*), live (*Quercus virginiana*), water (*Q. nigra*), southern red (*Q. falcata*), and northern red (*Q. rubra*) oaks. Results of a fallow study with the needle nematode indicate that control may be achieved with 1 year of fallow or crop rotations with a nonhost.

The host range test of the stunt nematode found that loblolly pine, several legumes, rye, and several sorghum varieties were good hosts for the nematode. Poor hosts of the stunt nematode included wheat, ryegrass, and oats. Pearl and brown top millet were found to be nonhosts of the stunt nematode. Additional research is needed to identify other hosts and nonhosts of the stunt and other nematodes, and the ability of nematodes to survive in the absence of a host.

Keywords: nematode, cover crops, host range, fallow, fumigation, *Tylenchorhynchus ewingi*, *Longidorus*, *Pinus taeda*, pine, *Quercus*, oak, sorghum, rye, wheat, legumes, cowpeas, vetch, alfalfa

Introduction

Plant-parasitic nematodes are common in forest tree nurseries, and some can become agents of damage when populations get above economic threshold levels. A survey of plant-parasitic nematodes in Southern forest nurseries by Hopper (1958) found that the majority of these nematodes occurred at low levels. Severe damage to pine seedlings was observed in only 3 nurseries where populations of stunt nematodes (*Tylenchorhynchus claytoni* or *T. ewingi*) or the pine cystoid nematode (*Meloidodera floridensis*) were high (Hopper 1958, 1959).

Presently, the potential threat of plant-parasitic nematodes to production in forest tree nurseries is difficult to assess. There has not been a survey of Southern nurseries for nematodes since 1958, and there is no mechanism or incentive for managers to report nematode damage. Recent fumigation studies in forest tree nurseries have found that nematode populations in control treatments were low and rarely differed from fumigated plots (Fraedrich and Dwinell 2003a,b; Kannwischwer-Mitchell and others 2003). In the past 6 years, only a handful of Southern nurseries had nematode related damage. Three nurseries were reported to have seedling damage from stunt nematodes (Carey 1999), and 1 nursery had seedlings damaged by a needle nematode (Fraedrich and Cram 2002).

Management options to control nematodes in forest tree nurseries primarily include sanitation, fumigation, crop rotation, and fallow. Nematicides, other than broad-spectrum fumigants, are not currently labeled for use in forest nurseries. Other cultural and biological control practices will not be discussed in this paper because they are mostly unproven and/or not applicable to forest tree nurseries.

Sanitation within a nursery typically means controlling soil and water movement from contaminated to uncontaminated areas. Equipment, irrigation, transplants, and even animals can move soil. In theory, a spreading weed host could also facilitate the movement of a plant-parasitic nematode. Sanitation can reduce the spread of a nematode, and combined with other management options, can help to control damage in a nursery.

Soil fumigation is one management option to depress nematode populations (Dropkin 1989); however, nematode population will often rebound (McKenry and Thomason 1976; Cram and others 2003; Fraedrich and Dwinell 2003c). Crop rotations of nonhosts or the use of fallow are other options to depress nematode populations (Dropkin 1989). Southern forest nurseries often use a combination of these options for control of nematodes and other soilborne pests.

Information on the species of nematodes that cause damage in forest tree nurseries is far from complete, and host range information on individual nematode species is often lacking. Recently, 2 species of nematodes have been discovered to attack loblolly pine (*Pinus taeda*). One nematode is a new species of needle nematode, *Longidoru*s spp., which is parasitic on loblolly as well as slash (*P. elliottii*) and longleaf (*P. palustris*) pines (Fraedrich and others 2003). Some work has been done on the host range by Fraedrich and others (2003); however, more information is needed on hosts such as white oak, which was grown in the field where this needle nematode was found (Cram and others 2003). The other nematode is a stunt nematode, *Tylenchorhynchus ewingi*, known to be pathogenic on slash pine (Hopper 1959). Information on the host range of this nematode is almost nonexistent. We have conducted a series of studies in recent years on these 2 nematodes species and potential control practices. This paper provides a summary of some of those studies and a discussion of the management implications for control of nematodes in forest tree nurseries.

Materials and Methods

Needle Nematode Studies

Fallow Study—The population density of the needle nematode was assessed in a fallow field at the Flint River Nursery, Montezuma, GA, from April 2002 until May 2003. The soil samples (6 to 10 cores) were taken in the top 15 cm (6 in) of soil from 10 *Longidorus*-infested plots located in 4 blocks of an infested field (Cram and others 2003). The *Longidorus* spp. were extracted from the 100 cc (6 in^3) of mixed soil by using the procedure outlined by Flegg (1967) and modified by Fraedrich and Cram (2002). This was our standard procedure for assessing population densities of the *Longidorus* spp. in soil. When the needle nematode was no longer detected in the plots, soil samples were then collected from the upper 30 cm (12 in) of soil in each plot and placed into 3 containers (1,600 cc/container [98 in^3/container]) per plot (30 containers total). Another 3 containers per plot (3 plots) were filled with soil from adjacent field areas with pine production and known to be infested with the needle nematode. All containers were planted with 5 loblolly pine seedlings. Containers were placed in growth chambers at 24 °C (75 °F) with 14-hr photoperiod. After 142 days, the *Longidorus* population densities were assessed using the standard procedure.

Oak Host Range—Six species of oak were tested for host suitability to the needle nematode. The oak species were live (*Quercus virginiana*), sawtooth (*Q. acutissima*), white (*Q. alba*), water (*Q. nigra*), southern red (*Q. falcata*), and northern red (*Q. rubra*). Loblolly pine and fallow treatments were also included. A soil of loamy sand was microwaved for 8 minutes in 2,000 g (70.5 oz) batches, and containers were filled with 1,600 cc (98 in^3) of soil. There were 4 replications (containers) of each species, and germinated oak and loblolly pine seeds were established in their respective containers (except the fallow containers). The containers were infested with 100 *Longidorus* spp. nematodes when the oaks were 15 weeks old and the pines were 7 weeks old. Containers were placed in growth chambers at 25 °C (77 °F) with a 14 hr photoperiod. After 13 weeks, the *Longidorus* population densities were assessed using the standard procedure.

Stunt Nematode Host Range

The host range of the stunt nematode, *Tylenchorhynchus ewingi*, was evaluated on loblolly pine and on 13 cover crops that were either used in the past or are used currently in Southern forest tree nurseries. The cover crops tested included forage sorghum (*Sorghum bicolor* 'ET-602' and 'Red Top Cane'), sorghum-sudan (*S. bicolor* 'SG Ultra' and 'Green Graze BMR'), wheat (*Triticum aesivum* 'VNS'), rye (*Secale cerale* 'Elbon'), ryegrass (*Lolium multiflorum* 'TAM 90'), oats (*Avena sativa* 'Mora'), pearl millet (*Pennisetum americanum* 'ET-300'), brown top millet (*Panicum ramosum* 'DW-01'), cowpea (*Vigna unguiculata* 'Pink Eye Purple Hull BVR'), vetch (*Vicia villosa* 'AU Early Cover'), and alfalfa (*Medicago sativa* 'Alfagraze'). A bare fallow treatment was also inoculated with the stunt nematode.

A loamy sand soil was microwaved for 8 minutes in 2,000 g (70.5 oz) batches, and containers were filled with 1,600 cc (98 in^3) of soil. There were 4 replications (containers) of each species, and 5 plants were established in each container (except the fallow containers). *Tylenchorhynchus ewingi* was extracted from stock cultures using a Baermann funnel method (Shurtleff and Averre 2000), and each treatment container was infested with 500 nematodes. Containers were placed in a growth chamber at 25 °C (77 °F) with a 15 hour photoperiod. Population densities of *T. ewingi* after 14 weeks were determined using the centrifugal flotation method (Shurtleff and Averre 2000). The numbers of nematodes from around the roots were also determined on a dry weight basis by soaking roots in approximately 1 L (0.25 gal) of water for 15 minutes, and then using the Baermann funnel method to extract the nematodes. Roots were dried for 48 hr at 80 °C (176 °F) and dry weights subsequently determined.

Results

Needle Nematode Studies

Fallow Study—The population density of the needle nematode decreased steadily during the first 101 days in the fallow field, and only a few nematodes were detected between 128 to 220 days (Figure 1). The nematode was not detected in soil samples from any plot on days 263 (January), 325 (March), or 365 (May). Soil that was collected on day 263 in the fallow fields and planted with loblolly pine did not have needle nematodes after 142 days in the growth chamber. The nematode was present in soil collected from an adjacent study area known to be infested with the nematode and grown with pine for 142 days (range: 9 to 38 nematodes/100 cc [6 in^3]).

Oak Host Range—Water, live, white, southern red, and northern red oaks were found to be hosts of the needle nematode, *Longidorus* spp. (Table 1). Sawtooth oak was the only species that had significantly less nematodes than loblolly pine, and the population density did not differ significantly from the fallow treatment. The final estimated population of the needle nematode per container of sawtooth fell below the initial inoculum level.

Stunt Host Range

Loblolly pine is a host of the stunt nematode, *T. ewingi*, and produced the most nematodes per gram of root on average (Table 2). Rye, the legumes, and the sorghum varieties were hosts for this stunt nematode. Wheat, ryegrass, and oats were poor hosts for the nematode based on the soil population density and total estimated populations. The final estimated population of stunt nematodes for containers with pearl millet and brown top millet fell below the initial inoculum level. Pearl millet was the only crop that had nematode population densities similar to the fallow treatment.

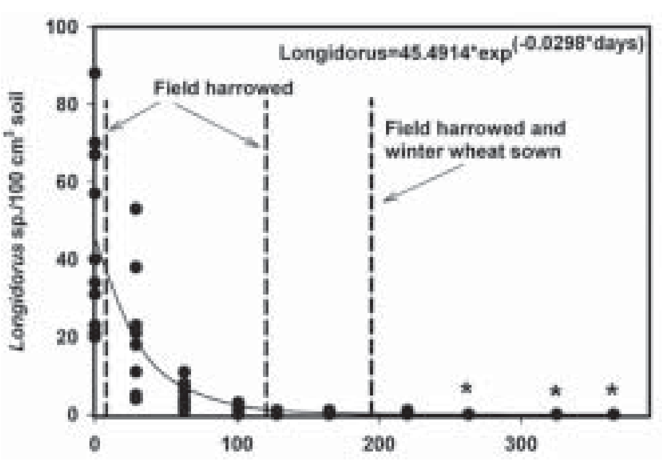

Figure 1—Relationship between the needle nematode (*Longidorus* spp.) population densities and days of fallow in field plots after April 11, 2002. Asterisks (*) at sample days indicate that the needle nematode was not detected in any field plot.

Table 1—Mean number of needle nematodes (*Longidorus* spp.) obtained from soil and roots of plant species 13 weeks after infestation with 100 nematodes/container.

Plant species	*Longidorus* spp./ 400 cc (24 in^3) soil[a]	Total estimated *Longidorus* spp. container
Loblolly pine	74 a	295
Water oak[b]	94 a	377
Northern red oak	56 ab	223
White oak[b]	42 ab	168
Southern red oak	33 ab	131
Live Oak	32 ab	129
Sawtooth oak	17 bc	69
Fallow	1 c	5

[a] Means followed by the same letter do not differ significantly (± = 0.05) according to Tukey's HSD test. Square root transformation of nematode counts was performed before analysis. Data were analyzed as a randomized complete block design.
[b] Means based on 3 replications.

Discussion

Nematode damage tends to surface in fields where nursery managers unintentionally provide an alternate host during crop rotations, or grow the same host continuously. A nematode population will build rapidly under conditions of continuously cropping of hosts (Dropkin 1989; Cram and others 2003). The new needle nematode species (*Longidorus* spp.), discovered in an experimental field at Flint River Nursery (Fraedrich and Cram 2002), originated in a block where loblolly pine production was alternated with white oak (Cram and others 2003). The discovery that white oak is a host of the needle nematode helps to confirm the suspicion that continuous cropping of host species led to the stunting of pine observed in this field. Unintentional use of alternate host crops also appears to have been a factor at another nursery where pine damage was caused by the stunt nematode, *T. ewingi*. The nursery personnel where the stunt nematode was found indicated that cowpeas were grown in the nursery prior to the first pine crop. They also reported using several sorghum varieties and rye as cover crops, all of which are now known to be hosts of this stunt nematode.

Fumigation has been found to depress high nematode populations (Dropkin 1989). Unfortunately, nematode populations can rebound quickly following fumigation and significantly impact subsequent seedling crops (McKenry and Thomason 1976; Cram and others 2003). The rebound of nematode populations after fumigation was demonstrated by Fraedrich and Dwinell (2003c) in a field infested with a *Longidorus* spp. Dazomet and metam sodium eliminated the needle nematode from the upper 15 cm (6 in) of soil, but populations subsequently increased during loblolly pine production to levels comparable to those in control plots by the end of the growing season (Fraedrich and Dwinell 2003c).

Nematodes are able to survive fumigation in a number of ways (McKenry and Thomason 1976) including: (1) a tolerant life stage (for example, cysts, cryptobiotic); (2) protected by plant tissue (endoparasitic); (3) present in soil below the toxic concentration of the fumigant; and (4) escapes fumigation due to restrictive soil layer or high soil moisture. If a

Table 2—Mean number of stunt nematodes (*Tylenchorhynchus ewingi*) obtained from roots and soil of plant species 14 weeks after infestation with 500 stunt nematodes/container.

Plant species	*T. ewingil* g root dry wt[a]	*T. ewingil* 100 cc (6 in^3) soil[a]	Total estimated *T. ewingil* container[a]
Cowpeas	5,230 ab	3,845 a	70,168 a
Alfalfa	252 cde	1,339 ab	23,056 a
Vetch (‘AU’)	4,502 a	1,209 ab	21,630 a
Sorghum sudan (‘BMR’)	293 bcd	834 ab	15,736 a
Loblolly pine	6,635 a	804 b	17,829 ab
Rye grain (‘Elbon’)	497 abc	790 ab	14,370 ab
Sorghum (‘Cane Sumac’)	1,338 abc	743 ab	16,626 a
Sorghum (‘ET-602’)	169 cde	669 ab	12,038 ab
Sorghum sudan (‘Ultra’)	178 cdef	309 bc	5,548 abc
Wheat (‘VNS’)	38 def	65 cd	1,146 bcd
Oats (‘Mora’)	31 def	49 d	830 cd
Rye (‘TAM-90’)	30 ef	45 d	949 cd
Brown top millet (‘DW01’)	29 fg	16 d	303 d
Pearl millet (‘ET-300’)	0 g	3 e	44 e
Fallow	—	3 e	40 e

[a] Means followed by the same letter do not differ significantly (± = 0.05) according to Tukey’s HSD test. Logarithmic transformation of nematode counts was performed before analysis. Data were analyzed as a randomized complete block design.

manager must use a field that is infested with a damaging plant-parasitic nematode and does not have time to fallow or grow a non-host in the field, then fumigation prior to sowing is the only management option. Fumigants that depress nematode populations include methyl bromide, chloropicrin, metam-sodium, 1,3-dichloropropene (Johnson and others 1979; Csinos and others 2000), and dazomet (Harris 1991; Fraedrich and Dwinell 2003c).

The fallow study with the needle nematode demonstrates that this nematode does not survive in soil for extended periods without a suitable host. Fortunately, the small grain cover crops normally used at the Flint River Nursery are not hosts for the needle nematode (Fraedrich and others 2003). The limited host range and inability of the nematode to survive for extended periods without a host helps to explain why this needle nematode has not been a problem at the nursery under their normal production schedule of 2 years of pine production followed by 2 years of cover crops or fallow. The new species of needle nematode has been found outside the nursery on water oak (Fraedrich, unpublished data) and in an adjacent pine seed orchard (Cram and others 2003), which could provide a source for reintroduction in nursery fields through soil and water movement (floods, equipment, wind, and animals). However, the nursery should not have a serious problem with this nematode in the future, based on the host range and survivability of the needle nematode in fallow soils.

The results of the host range test on the stunt nematode, *T. ewingi*, indicate that legumes can be excellent hosts for these nematodes. At one time, legumes were preferred as a cover crop in Southern nurseries because they provided nitrogen to the soil (Wakeley 1954). More recently, nursery managers have favored small grains such as sorghum, rye, and brown top millet as cover crops. Unfortunately, the results of our study suggest that various sorghum varieties and grain rye may be good hosts for this stunt nematode. Managers may wish to favor grains such as pearl or brown top millet in place of sorghum, sorghum-sudan, or rye (grain) in fields where this nematode has been a problem.

The use of fallow or alternating hosts with non-hosts to control parasitic nematodes can be highly effective. Knowledge of the host range and survivability in the absence of a host are essential to effectively applying these cultural control methods. More work is needed to evaluate the suitability of various cultivars of potential cover crops for the stunt nematode (*T. ewingi*) and other nematodes commonly found in forest tree nurseries. Information on the survivability of this and other nematodes in the absence of a host would help establish the length of time a field would need to be in nonhost cover crops or fallow to control individual species of nematodes.

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Active Nursery Projects at the Missoula Technology and Development Center

Brian Vachowski

Brian Vachowski is Program Leader for Nurseries, Reforestation, and Range at the Missoula Technology and Development Center (MTDC), 5785 Highway 10 West, Missoula, MT 59808; telephone: 406.329.3935; e-mail: bvachowski@fs.fed.us

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Abstract: The USDA Forest Service Missoula Technology and Development Center (MTDC) provides technical expertise, new equipment prototypes, and technology transfer services to Federal, State, and cooperator forest tree seedling nursery managers. Current projects at MTDC include a nursery soil moisture meter, remote data collection systems, low cost weather stations, soil compaction tester, shielded herbicide sprayer, seedling wrap, copper treatment for Styroblocks™, and whitebark pine seed scarifier. Recently completed projects include nursery soil sterilization, hardwood cuttings preparation equipment, and seed orchard duff sweeper.

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

Introduction

Missoula (MTDC) and San Dimas (SDTDC) Technology and Development Centers serve the USDA Forest Service by helping to solve problems identified by field employees. For nearly 40 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 main 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 Forest Management staff group at the Washington Office, and through State and Private Forestry.

Our focus at MTDC is on applied technology and technology transfer. We are not part of the Research and Development branch of the USDA Forest Service. Rather, we apply research findings to help solve on-the-ground problems.

Projects originate from ideas or concepts from field personnel. A national steering committee reviews the project proposals that typically come from employees at the Forest Service Federal nurseries, and from State and private cooperators. The steering committee selects the highest priority projects for MTDC to work on. In any given year, there are about 20 to 25 active reforestation and nurseries projects.

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 usually document our projects through printed reports or journal articles that are available from MTDC.

Current Nursery Projects at MTDC

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 2 instruments, Campbell Scientific TDR (time domain reflectometry) probes, models CSI-615 and CSI-616, looked 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 formulae customized to reflect soil characteristics at individual nurseries. We have lab tested the probes to see the effects of soil variables on the TDR readings. The next step is to evaluate the probes at USDA Forest Service Coeur d'Alene Nursery in Idaho under field conditions and compare the results with the laboratory baking method.

Remote Data Collection Systems

Project Leader Gary Kees is evaluating remote sensors, monitored via satellite, which will tell silviculturists when distant sites are ready for outplanting. Satellite communication and the needed ground sensors are becoming much less expensive than in the past, and Gary believes it may be possible to measure snow depth and soil temperature remotely for approximately U.S. $1,000 per setup. MTDC is testing 3 AXTracker satellite transmitters to determine if this is a practical, affordable, and dependable technology.

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. As part of the Remote Data Collection project, MTDC is evaluating low-cost weather instruments that have data logger capabilities (Figure 1). We purchased 2 different systems for U.S. $600 and U.S. $1,300, and plan to evaluate them.

Figure 1—Downloading data is relatively easy on these low-cost weather stations.

Project Leader Gary Kees hopes that if they work well, these less expensive systems will provide good alternatives 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.

Soil Compaction Tester

A tree planting contract inspector approached MTDC with a proposal to develop a fool-proof, low-cost method to determine soil compaction around planted seedlings to determine whether contract specifications had been met. The traditional method for inspecting compaction is to dig a test hole alongside a sample of planted seedlings and determine compaction by visual inspection.

MTDC evaluated 3 electronic soil penetrometers on the Shasta-Trinity and Boise National Forests (Figure 2). Unfortunately, for tree contract inspection, the penetrometers gave inconsistent results and are not recommended. The electronic penetrometers do 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. Project Leader Gary Kees plans to document his findings and the availability of this new generation of soil penetrometers. He plans to do further evaluation of the penetrometers at the Coeur d'Alene Nursery in 2004.

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 was asked to review this existing equipment, select the best features, and incorporate those features into a new prototype model.

Figure 2—New-generation soil penetrometers are easy to use, and save readings for further analysis back at the office.

Project Leader Keith Windell worked with machinery developed by several Southern nurseries. He 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 9 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 (see South, this proceedings; Stallard, this proceedings).

Field testing was done at the Virginia Department of Forestry New Kent and Augusta nurseries. Two deficiencies became evident. Steering was blocking the view of the ground, making it difficult to precisely steer the machine. Also, the shields were digging into soft ground. MTDC modified the sprayer by redesigning the steering, adding height gauge wheels, and adding a more precise hood width adjustment (Figure 3). The Virginia nurseries are retesting the sprayer, and MTDC has construction drawings available upon request for the improved prototype.

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. Contact Brian Vachowski for more information.

Figure 3—MTDC's improved shielded herbicide sprayer is being evaluated in Virginia.

Copper Treatment for Styroblocks™

Copper-coated Styroblocks™ are the containers of choice for some nurseries as the benefits of the containers become better understood. These benefits include ease of seedling extraction, reduced root spiraling, improved seedling development, reduced buildup of root disease inoculum, and longer usable container life.

Copper-coated Styroblocks™ can be purchased from Stryoblock™ manufacturers, but the coating wears off after about 2 growing cycles. MTDC was asked to look at methods and equipment to recoat the containers with the copper treatment, assuming it is feasible to do so.

After evaluating the economic and environmental feasibility of the recoating process, MTDC determined that it would not be in the government's best interest to further pursue developing a recoating machine. We do not plan any further development work on this project. There may be some private-sector potential to developing a recoating machine. Gary Kees is the contact for more information.

Styrofoam™ Container Sterilizer

The MTDC is looking at methods and equipment to sterilize Styroblocks™ before filling them with media and sowing seeds. Certain pathogens like *Pythium* spp. and *Fusarium* spp. remain in the residual media and in some roots that may remain after the seedlings have been extracted.

Many nurseries dip their used containers into hot vats of water (160 to 180 °F [71 to 82 °C]) and hold them there for at least 2 minutes. This method works, but is slow and labor intensive. A typical nursery can dip only about 25 to 30 containers at a time, but must sterilize thousands of containers each year.

The MTDC has been looking at alternative methods of sterilization. We first looked at infrared heat, but we could not provide enough heat to the inner cavities without melting the tops of the containers.

Next, we looked at using microwave or radio frequency waves, using a large radio frequency oven made for drying. The MTDC tested several Styroblocks™ at various exposure durations and found that the oven was effective at reducing pathogen levels to acceptable levels, but the equipment costs were excessive.

We also evaluated steam heat, like that in a sauna, and found that it will effectively sterilize the containers. The concept is that a large room could be constructed where pallet loads of containers could be treated at one time. The containers could be left in the oven for a specific period of time, then removed. Preliminary testing indicates that the Styroblocks™ must be wetted or sprayed down before heating.

Project Leader Andy Trent is currently working with the USDA Forest Service Lucky Peak Nursery near Boise, Idaho, to install a steam boiler and distribution system to test this concept on an operational level.

Whitebark Pine Seed Scarifier

Whitebark pine is being planted 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% natural germination, to more than 60% germination if there is a 1-mm cut in the seed coat. Now each seed is being cut manually with an Exacto knife, a tedious process that presents its own set of safety concerns.

The 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 seed lots.

We are currently testing a less complex prototype, which consists of sandpaper-lined cans that rotate in an orbiting pattern (Figure 4). Coeur d'Alene Nursery staff are currently evaluating it to see if it meets the need. Andy Trent is Project Leader.

Recently Completed Nursery Projects

Nursery Soil Sterilization

Methyl bromide has been the preferred method at most nurseries for fumigating soil to combat soil pathogens. However, methyl bromide has been found to be environmentally harmful, and its use may be banned or severely restricted. The MTDC was asked to look at alternatives to chemical fumigation for tree seedling nurseries.

Looking at an older technology still used in Europe in agricultural applications, MTDC built a prototype steam treatment machine for treating nursery beds. If soil is heated to at least 160 °F (71 °C) for 20 minutes, tree seedling pathogens are killed, while desirable microorganisms survive. The MTDC's steamer featured a 1-million BTU boiler that has been outfitted to inject steam into the soil at about 8 in (20 cm) deep. Field testing of the steamer concluded that it effectively controlled the pathogens, but the prototype machine was too slow for field production use. Test results are documented in *Nursery Soil Steam Fumigation* (9724-2833-MTDC), available from MTDC.

A British firm, UK Sterilizers, reportedly had a mobile soil sterilizing machine that they were hoping to test in the United States in late 2003. We have not heard from that company for over a year, but will continue to try to make contact to see whether their machine works.

As another alternative, we are evaluating infrared heat for sterilizing the soil. In theory, infrared or radiant burners should be much more efficient in heating the soil than steam. The idea is to lift soil from the soil bed onto a conveyor belt where infrared burners mounted 12 in (30.5 cm) above the conveyor will heat the soil. Project Leader Gary Kees is conducting preliminary tests to determine if this concept warrants full field testing.

Hardwood Cuttings Preparation Equipment

The 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 (Figure 5). The saw was tested at the USDA Forest Service Bessey Nursery in Halsey, NE, early in 2003, and MTDC has drawings and a report available.

Seed Orchard Duff Sweeper

Duff in seed orchards harbors insect larvae over winter. Starting with a machine designed to sweep golf courses,

Figure 4—This whitebark pine seed scarifier is being evaluated at the USDA Forest Service Coeur d'Alene Nursery, Idaho.

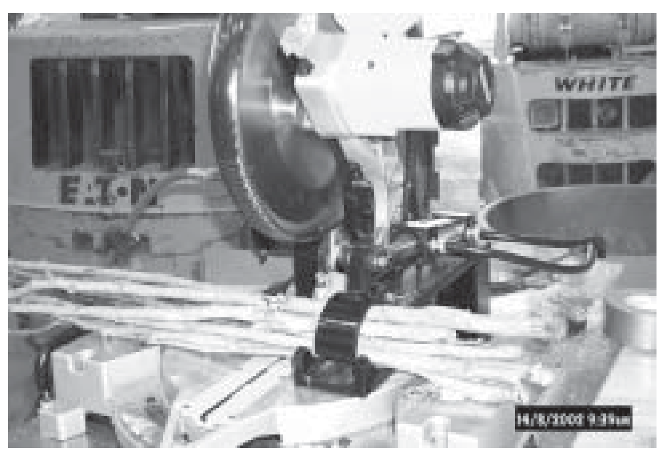

Figure 5—This miter saw features a foot-operated clamp to safely and securely hold bundles of tree whips being prepared as cuttings.

Project Leader Keith Windell developed a prototype duff sweeper that removes the infected duff from the seed orchard floor. He also developed a collection device for the duff. The project was funded through MTDC's Forest Health Program and State and Private Cooperators in the Northwest.

Contacts for More Information

A complete listing of the nursery 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/. The list is also included in the printed report, *Reforestation & Nurseries* (0224-2805-MTDC), available on request by calling 406.329.3978. Drawings and reports that are available in electronic form are available to the public at:

http://www.fs.fed.us/eng/t-d.php.

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Mechanized Symmetrical Sowing

Kirk D. Howell

Kirk D. Howell is with Timberwolf International, Inc., PO Box 26, Auburn, GA 30011; telephone: 770.995.5242; e-mail: timberwolfhowl@msn.com

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Keywords: bareroot seedlings, seedling density, loblolly pine, vacuum seeder

Introduction

With hundreds of variables to investigate, and thousands of combinations, seldom is there found such appeal to the investigator as an organism's response to density. Loblolly pine (*Pinus taeda* L.) was grown at several levels of seedbed density and sowing configurations in order to display unique contrasts between consequent morphological traits, expense investments, and respective grades in revenue potential.

Seed sowing has advanced much over the past century. Only 50 years have passed since the Whitfield seeder replaced the Hazard seeder (May and others 1984), bringing precision to an already mechanized sowing process. Appropriately identified as "precision sowing" due to calibrated seed placement, greater seedling uniformity was realized. However, specifications require that the vacuum drum be restricted to 6 inches between the rows in order to satisfy cultural practices of lateral root trimming and seedling lifting. This 6-inch constraint precluded increasing seedbed density, since seedlings would have to be crowded within the row. In order to sow seedlings symmetrically, the 2- and 3-inch vacuum sowing drums were conceived. Unlike Hazard sowing, seeds were sown with precision by narrowing between-row spacing in order to extend within-row spacing.

In a 1999 nursery study (Howell 2001), symmetrical sowing was performed using a hand-sowing press to make soil impressions. The study lacked a proper comparison between 2 mechanized systems, however, because the 2- and 3-inch vacuum sowing drums were not available. Results of that study demonstrated that symmetrical sowing maintained typical seedling sizes at higher seedbed densities, and larger seedlings were produced at standard densities. The objectives of this study were (1) to demonstrate how increased seedbed densities can reduce production costs and permit nurseries to lower prices if needed, (2) to maintain seedling size (diameter and height) and uniformity by sowing in symmetry, and (3) to improve stem form.

Methods

This study involved sowing second generation loblolly pine seeds at Taylor Nursery (South Carolina Forestry Commission) in Aiken County over 4 beds at 4 by 380 ft each. Three vacuum sowing drums, drilled at 2, 3, and 6 inches between rows, were used to sow seeds at 5 seedbed densities (16, 25, 36, 49, and 64 drills/ft^2 [Table 1]). See Figure 1 for a visual configuration perspective. The 4 replicated beds (380 ft) were segmented into 2 blocks of 190 ft each; the replicated blocks held 15 individual 10-ft units for each treatment combination with 2-ft separation between units (Figure 2). The term "drills/ft^2" represents the seed sowing positions, which is synonymous with seedlings/ft^2, to be adjusted by survival.

Nursery Procedures

In early May 2003, all seedbeds were plowed, shaped, and pressed after the usual standards practiced at Taylor Nursery. Before sowing, each drum was calibrated to ensure accurate sowing density for each treatment.

Table 1—Conversion tables for area, length, and seedling densities throughout the paper.

	English	Metric
Area	1 ac	0.4 ha
	1 ft^2	0.9 m^2
Distance	1 in	2.5 cm
	1 ft	0.3 m
Seedling densities	16 seedlings/ft^2	178 seedlings/m^2
	25 seedlings/ft^2	278 seedlings/m^2
	36 seedlings/ft^2	400 seedlings/m^2
	49 seedlings/ft^2	544 seedlings/m^2
	64 seedlings/ft^2	711 seedlings/m^2

Analytical Procedures

Cost Estimation

Land (space), labor, and material costs were accounted (Table 2). All costs are reported in U.S. dollars ($). The workable land carries a specified cost per acre, which is unique to the region, and was set for this example at 35,000 ft^2/usable-ac or about 20% less than 43,560 ft^2. For each density, I calculated the amount of acreage required to produce 10 million stems.

For the required acreage, I calculated a labor cost in person-hours/year. Only area-specific labor costs were considered here, since overhead costs and other implicit costs have little to do with production acreage. Some examples of area-specific costs are fumigation, bed preparation, fertilization, sowing and lifting, herbicide and pesticide applications, irrigation, lateral root trimming, root undercutting, and top trimming. I based my standard on a scenario where

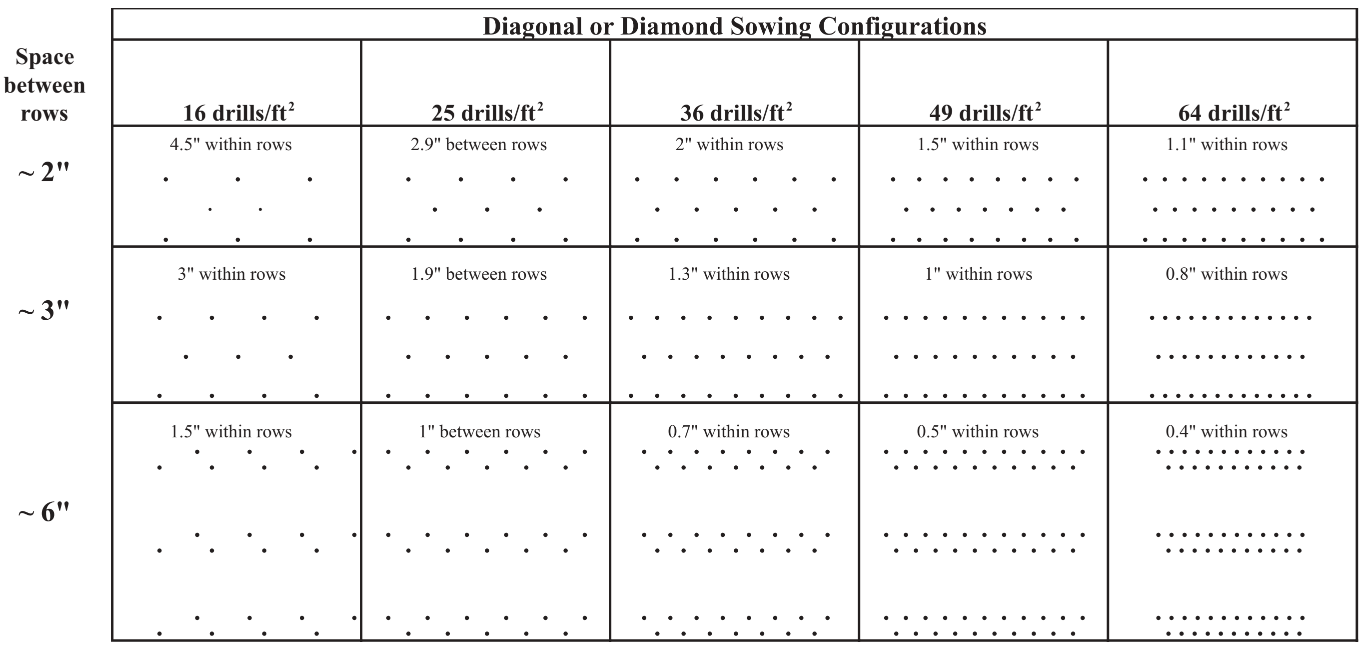

Figure 1—Sowing configurations of treatments involving 3 vacuum drums, drilled at 2, 3, and 6 inches between rows, and 5 seedbed densities of 16, 25, 36, 49, and 64 drills/ft^2.

Sowing Densities (drills/ft^2)				
16	25	36	49	64
1	2	3	4	5
6	7	8	9	10
11	12	13	14	15

3 3 3 3

8	11	3	12	14	15	6	4	2	13	10	5	7	9	1
2	9	12	13	6	10	8	14	5	3	11	1	15	4	7
15	1	7	4	9	5	13	3	8	12	2	6	10	11	14
4	5	10	6	11	1	12	7	9	15	3	8	14	13	2

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1	8	9	15	7	13	3	11	2	14	6	5	10	4	12
14	2	12	3	4	8	1	6	5	15	10	11	13	7	9
4	15	10	2	5	6	11	9	7	1	3	12	14	8	13
11	13	14	6	9	12	10	5	3	8	7	4	2	15	1

3 3 3 3 3

Figure 2—The treatment layout with 4 replications of 380 ft seedbed lengths as partitioned into 2 blocks. Each 10-ft treatment replication (5 densities by 3 sowing drums) was separated by 2 ft.

Table 2—Cost estimates (all in U.S. dollars [$]) as affected by area-specific trials according to the factors of Space, Labor, and Material with respect to density. Cost items were first based on calculating the numbers on 35,000 ft^2/usable-ac or about 20% less than 43,560. Then the needed acreage for 10 million seedlings produced (10M) was calculated. Next, the cost of space utilization as rent with a hypothetical per-acre rent of $100 was figured. Labor costs are first calculated by estimating person-hours (based on about 400 hours/yr for the standard of 25/ft^2) required to work respective land area, multiplied by a 4-person work force, and again multiplied by an assumed average wage of $15/hour. Material costs were based on a $20,000 cost to produce seedlings for the standard of 25/ft^2. The total combines all costs.

Cost items	**16/ft^2**	**25/ft^2**	**36/ft^2**	**49/ft^2**	**64/ft^2**
	density				
No. on 35,000 ft^2/ac	560,000	875,000	1,260,000	1,715,000	2,240,000
Acres for 10M stems	17.9	11.4	7.9	5.8	4.5
Spacial rent $100/ac	$1,786	$1,143	$794	$583	$446
Person-hours 400/yr	625	400	292	225	180
4 persons * hrs/person	2,500	1,600	1,168	900	720
Labor costs $15/hr	$37,500	$24,000	$17,520	$13,500	$10,800
Material costs	$31,250	$20,000	$13,889	$10,204	$7,813
Total costs	$70,536	$45,143	$32,203	$24,287	$19,059

Conversion note: 1 ac = 0.4 ha; 16 seedlings/ft^2 = 178 seedlings/m^2; 25 seedlings/ft^2 = 278 seedlings/m^2; 36 seedlings/ft^2 = 400 seedlings/m^2; 49 seedlings/ft^2 = 544 seedlings/m^2; 64 seedlings/ft^2 = 711 seedlings/m^2.

one individual is required to work 400 hours/year for the crop of 10 million seedlings at the standard density of 25 stems/ft^2. This becomes the pivotal point from which to determine the labor required to work all the other densities. To simulate a 4-person crew, hours/year were multiplied by 4, and a supposed $15/hour average wage was multiplied to get a labor cost/year for the crew for each density. Higher densities were penalized due to lags in lifting by 5, 10, and 15% with respect to 36, 49, and 64 stems/ft^2, caused by an increase in density and relative root binding. Besides any cost inflation from this hypothetical evaluation (Table 2), "real world" labor hours and costs can change with time, region, and worker experience, and must be adjusted according to nursery specifics.

Material costs, which were estimated at $20,000 to produce 10 million stems at 25 stems/ft^2, were proportionally based for other densities. The total area-specific production cost for each density was then determined by adding the estimated costs of space, labor, and material.

Seedling Measurements

To determine the effect of density and between-row configuration on seedling growth, measures of height and diameter for 10 randomly selected seedlings per treatment-replication were measured at the end of the growing season. At the time, seedling survival, uniformity, and cull percentages were also assessed for each treatment replication.

Stem form manifests its influence as the denominator of volume equation, as follows:

$$\textbf{Volume} = (\pi * \text{radius}^2 * \text{height}) / \text{form}$$

where "form" approaching "2" (>1.5) is parabolic, and approaching "1" (<1.5) is cylindrical.

Data Analyses

All measurable data were analyzed using the analysis of variance (ANOVA) procedure in SAS (SAS Institute 1989), and the Tukey's mean separation procedure was employed for the comparison of main effects. Differences were significant at $\alpha \leq 0.05$.

Results and Discussion

Evaluating Costs

Reducing seedling costs may not be just an option, but a necessity in the event of (1) a declining consumer demand, and/or (2) an increased competitive environment. Increasing seedbed density is an option for cutting production costs and lowering prices. My first objective was to demonstrate how changing seedbed density affected land, labor, and material costs, and thus a nursery's ability to lower the price of seedlings with respect to yield (that is, seedling quantity and quality).

Changing density changes land rental costs. Starting with our standard of 25 stems/ft^2, decreasing seedbed density to 16 stems/ft^2 offered a quantity of 560,000 seedlings/usable-acre, instead of the standard 875,000/usable-ac (Table 2). Increasing density to 36/ft^2, 49/ft^2, and 64/ft^2 gave quantities of 1.26, 1.72, and 2.24 million seedlings/usable-ac, respectively. Assuming a nursery production of 10 million seedlings, the acreage needed for each treatment-density ranged from 17.9 ac at 16/ft^2 to only 4.5 ac at 64/ft^2. After applying $100/ac rent, the cost of occupying respective areas would range from $1,786 to a low $446. Although dollar values must be adjusted by the specifics of a given region, proportional differences will remain as established.

This ability to produce 10 million seedlings on less land offers substantial savings in cost (rent), and releases the unused portion for other resourceful prospects for opportunity. Because usable land seldom remains idle, less labor to work fewer acres offers the nursery additional savings. I made several assumptions to illustrate this, and these must be adjusted according to the specifics of each nursery. After assigning 400 hours/year to my 25/ft^2 standard and 1,600 hours for a 4-person crew, crew hours ranged from 2,500 hours to work 18 ac to as little as 720 hours to work 4.5 ac. In this example, higher densities were slightly penalized by 5, 10, and 15% for 36, 49, and 64/ft^2, respectfully, since higher numbers/ft^2 require more labor due to lags during the lifting process. Multiplying crew hours by $15/hour offered a total labor cost for each density (Table 2), separating the highest and lowest density by about $27,000 for the 10 million seedlings produced.

The cost of obtaining area-based materials (substances, items, products, and so on) involved in cultivating 10 million seedlings was the remaining factor to be estimated. Based on my estimate of $20,000 for the standard density (25/ft^2), area-based material costs ranged from $31,250 covering 18 ac to only $7,813 for 4.5 ac. Because material costs depend upon the cost of products supplied and a nursery's protocol, my estimate of material costs must be tailored according to a nursery's empirical information.

Ability to Lower Price

According to my estimates, area-based operating costs from densities of 16, 25, 36, 49, and 64/ft^2 were $7.05, $4.51, $3.22, $2.43, and $1.91/1,000 seedlings, respectively. This translates into a difference of $5/1,000 seedlings from 16 to 64/ft^2, and about $2/1,000 from 25 to 49/ft^2. Certainly, other fixed costs that can be cut and other costs, unaffected by area, such as overhead, interest payments, investments, and so on, need to be addressed. Additional costs may be substantially greater than area-based costs (for example, $25/1,000 other costs versus $7 to $2/1,000 area-based costs). A small cost reduction of $2/1,000 is well worth any reasonable investment, since it increases the "profit margin" built within the "asking price." The discrepancy between a nursery's asking price and the price a consumer is willing to pay may have huge implications; sometimes a mere $2/1000 can determine whether a nursery breaks even, makes a profit, or suffers loss (Hodges and D'Ambrosio 1996).

Consumer Demand

Estimating consumer demand is an obstacle that nursery managers must consider. In my example, the supply of 10 million seedlings met demand exactly; this is not realistic. In reality, nursery managers have the difficult task of trying to predict a supply level according to past trends, where over-projections may result in plowing millions of seedlings under. Invested dollars in terms of space, labor, and material must be recovered with product sales. Suppose from 15 million seedlings cultivated only 10 million were sold, and 5 million had to be plowed under. The money ($2.5/1,000 at 25/ft^2, $1.3/1,000 at 49/ft^2, and so on) invested in those extra 5 million seedlings are costs to be recovered from the 10 million seedlings sold. On the other hand, to underestimate consumer demand can also be quite costly. The penalty is in terms of lost revenue and turning customers away due to a sold-out supply.

Larger Stem Size—Increased Revenue Potential

Revenue can be realized through increased seedling sales (that is, production quantity), but the potential to generate revenue is greatly increased when elevating the asking price for large seedlings. Suppose nursery "A" sells loblolly pine at $40/1,000 for seedlings with ground-line diameters between 4 and 5 mm, and nursery "E" sets a price at $45/1,000 for the same. Except for genetic aspects of improved quality, a nursery's ability to raise prices can be limited. However, large seedlings with average ground-line diameters of 6.5 mm (that is, improved morphological quality) can be sold for higher prices because they promise the landowner a morphological advantage. Thus, assume that nursery "I" sells high-grade seedlings for $74/1,000, and standard-grade seedlings (like those of nurseries "A" and "E") for $50/1,000. Certainly nursery "I" is given a tremendous incentive in charging $24/1,000 on top of $50/1000, which translates into an extra $240,000 for 10 million seedlings. How does this benefit the landowner?

The Landowner's Reward

Large seedlings hold a morphological advantage; but how great is that advantage and are landowners willing to pay more for it? Figure 3 illustrates how that after 1 year in the field with a site index of 80 ft and a base age of 50 years, stems with an average height of 45 cm would have diameters ranging from 7 to 10 mm. I used a diameter-to-height ratio where diameter = height * 0.2 $\pm$ 0.03. This suggests that landowners establishing plantations with such seedlings are reducing rotation length to harvest by 1 year provided no lags in seedling growth are caused by planting shock. When planted properly, survival and growth of larger stems should increase (South 1993). A 2-year gain at establishment would require either accelerated growth or planting stems with an average height of 28 in and diameters ranging from 11 to 16 mm. This is probably unlikely. Nevertheless, reducing rotation lengths enables landowners to receive a financial return on their investment sooner (Clutter and others 1983).

Because the interest rate is quite unpredictable, it is essential for plantation costs to be held to a minimum. My example in Table 3 shows how reducing a pulpwood rotation length by 1 year (from 11 to 10 years) offers the landowner a discount of $18/ac and $52/ac at 4 and 8% interest, respectively. The 4% increase in interest offers the landowner even more incentive ($34/ac) to reduce rotation length and to minimize initial costs of establishment. Now suppose the landowner typically makes a $300/ac investment, which includes site preparation ($175/ac), seedlings ($50/ac), and planting ($75/ac). An owner spending $24/ac more for advanced seedlings from nursery "I" can harvest 1 year sooner; there is no change in future costs.

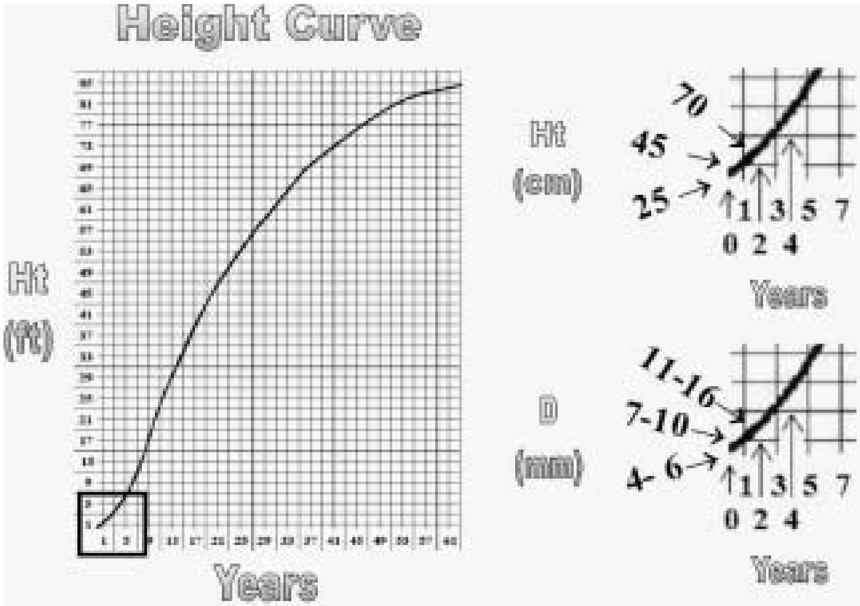


Figure 3—The first 7 years taken from a height curve, 80 ft in height and a base age of 50 years, whereby corresponding diameters measurements were determined using a diameter-to-height ratio of diameter = height * 0.2 ± 0.03.

Finding Middle Ground

The nursery/landowner relationship must be based on mutual benefit for the long-term benefit of both entities. Suppose nursery "U," by utilizing an innovative practice like symmetrical sowing, finds the ability to increase seedbed densities to produce seedlings of both grades (common and advanced). With decreased costs of production, nursery "U" realizes its ability to lower prices to absurd levels of $33/1,000 for common grades and $44/1,000 for advanced grades, and still make a profit. However, in order to maintain market stability (Tomek and Robinson 1990), nursery "U" decides to maintain price levels of advanced stems at $60/1,000 (Table 3), which is just $10/1,000 above and $14/1000 below respective common grades ($50/1000) and advanced grades ($74/1,000). Therefore, the landowner spends only $10/ac instead of $24/ac more for advanced seedlings from nursery "U", enjoys a return on the investment 1 year sooner, and also realizes a future cost savings (at 8%) of $30/ac. Hence, nursery "U" becomes profitable through innovation, and shares the benefit with the landowner.

Table 3—Future cost implications (in U.S. dollars [$]) as affected by factors of initial establishment costs, interest rate, and the number of years carried. The first scenario shows the savings at 4% ($18) and 8% ($52) when harvest is realized 1 year sooner (from 11 to 10 years), due to the planting of larger seedling sizes (at least 7 mm diameter). The next scenario illustrates how much money can be saved ($34) when interest rate changes from 4 to 8%. The final scenario shows the effect of increasing the initial establishment cost by $24 (harvest 1 year sooner) instead of by only $10 (harvest 1 year sooner, and save in $30 in future costs) for larger seedling sizes.

Cost/ac ($)	Rate (%)	Yr A	Yr B	Yr A ($)	Yr B ($)	Save ($)
300	4	11	10	462	444	18
300	8	11	10	700	648	52
324	8	10		700		**34**
24		**1**		**0**		
310	8	10		670		
10		**1**		**30**		

Seedling Size in Present Study

While production costs represent the investment, seedling survival and size (that is, yield) represent the payoff. The yield results (Table 4) from this study also varied distinctly with seedbed density, and symmetrical sowing served to maintain various aspects of yield at higher densities. Perhaps the most important aspect is emergence and survival (seedling presence). Final seedling presence did not vary significantly with density or sowing configuration, except for the standard (25/ft^2) where 86% was the lowest value. This seems to be an aberration, however.

Diameters differed significantly among densities (Table 4), except between those of the 2 highest densities. As expected, the largest diameters were found at the lowest density, regardless of configuration, and more than 1 mm separated diameters from the lowest density to the highest density. Diameter range illustrates how uniformity increases when seedlings are crowded, and the lowest ratio illustrates this with the highest densities. The drawback to increased uniformity is seedling suppression. Hence, without additional growth enhancements at high densities (for example, extended growing time, increased fertilization, and so on) there will be too many culls. This is illustrated with over 70% culled when the criteria is set at a 4-mm diameter limit. Had sowing been performed 1 month earlier (April rather than May) or fertilization increased, cull percentages might have been closer to those shown under the 3-mm diameter limit.

Table 4—Yield items reported include survival, diameter, range, seedling culls below 4 mm diameter ($Cull_4$) and below 3 mm diameter ($Cull_3$), and height with respect to density and between-row spacing (Drum).

Yield items	Density														
	16/ft²			*25/ft²*			*36/ft²*			*49/ft²*			*64/ft²*		
Drum Y	2"	3"	6"	2"	3"	6"	2"	3"	6"	2"	3"	6"	2"	3"	6"
Survival (%)	94	92	92	84	85	88	90	94	84	94	90	84	94	91	94
Diameter (mm)	5.3	5.5	5.2	4.7	5.1	4.8	4.6	4.5	4.6	4.1	4.3	4.2	4.0	4.0	3.9
Range (mm)	2.2	1.9	2.7	1.6	2.1	2.0	1.8	1.8	2.1	1.7	1.8	2.2	1.8	1.7	1.4
$Cull_4$ (%)	5	6	9	19	10	11	22	31	33	54	43	53	67	72	73
$Cull_3$ (%)	0	1	2	4	3	3	4	8	13	13	6	16	17	22	21
Height (cm)	23	24	23	25	23	24	27	27	26	28	27	25	28	29	27

Conversion note: 16 seedlings/ft^2 = 178 seedlings/m^2; 25 seedlings/ft^2 = 278 seedlings/m^2; 36 seedlings/ft^2 = 400 seedlings/m^2; 49 seedlings/ft^2 = 544 seedlings/m^2; 64 seedlings/ft^2 = 711 seedlings/m^2.

High-density, symmetrically sown seedlings were significantly taller than low-density seedlings, regardless of configuration. Had top pruning been permitted, height would not have been a factor, and the interesting phenomenon caused by crowding would not have been demonstrated so thoroughly. Since top pruning is not performed in all southern pine nurseries, it is evident that some landowners and managers favor taller stems and are willing to forgo the benefits of top pruning (for example, to forgo increased root growth and the preferable root-to-shoot ratio).

Stem Form

Although not quantified statistically, differing sizes from respective densities and configurations can be depicted according to stem form. The highest densities configured with a between-row spacing of 6 inches seemed to favor lateral branching over height growth, perhaps due to the effect of more edge. The greatest benefit to crowding (Figure 4A) is expected to suppress lateral branches on 4 sides, because sowing in symmetry is designed to reduce the edge effect. In horticulture, 2 factors are required to form a bush. First, ensure that sunlight can reach the lower portions of the trunk (for example, create edge by lowering density). Second, eliminate apical dominance by repeated top trimming (Davidson and others 1994). Consequently, the impact of some current nursery practices, and their favored stem form, may maintain that form in the field for years to come, but this is my hypothetical assertion.

End Product

It is open to debate whether there are long-term consequences from specific seedling cultural practices, but short-term effects appear to be quite evident on early plantations where bushes seem to be ubiquitous (Figure 4B). How much of what we see in the field (at any stage) can be attributed to nursery training? In my opinion, when bushes are planted at relatively low plantation densities, low-lying branches tend to receive more sunlight and can remain free-to-grow with vigor; hence, they have the propensity to linger longer on the tree trunk. However, I hypothesize that when poles, having weaker lateral branches, are planted in similarly low plantation densities, the lower limbs are prone to abscise sooner (as depicted in Figure 4B); hence, allowing vital nutrients to be allocated to basal and apical growth. Long term, it would be a more "passive" form of forest management to permit stems with excessive, low-lying branches to remain unchanged on the plantation. Not correcting this condition may actually be more expensive than manually removing unnecessary branches (creating poles) and helping increase main-stem growth, better utilizing growing space, and improving log quality (Figure 5). Again, I mention several hypotheses that need to be statistically substantiated.

Research to Come

Besides a thorough investigation of my speculation concerning the occurrence of lateral branches in plantations due to nursery practices, prospective research should also examine various plantation densities in order to find maximum stand and single-stem yield, while lowering the costs of establishment. Accelerated diameter and height growth was demonstrated for high plantation densities (1,180 trees/ac) over that of lower density plantations (120 trees/ac) of Douglas-fir trees through the fifth year after planting (Woodruff and others 2002). This indicates that there is a window of time to work within before stand closure, whether for nursery or plantation. However, upon determining the point in time when crowding begins to suppress diameter growth, a release or harvest is warranted. Typically on plantations, the only release option exercised is to thin the stand by removing trees. However, lateral branch pruning is a release that could extend a few more years to high-density plantations. More than 50 years have passed since Harold Young and Paul Kramer (1952) demonstrated that the elimination of lateral branches accelerates height growth and decreases stem taper. These principles have yet to be adequately demonstrated in the field, where the greatest benefit in pole production is anticipated by design to increase revenue potential.

Recommendations

In my opinion, symmetrically sowing with 2- and 3-inch sowing drums seems to advocate production of pole-shaped stems, because low-lying lateral branches appear to be more effectively impeded, but configuration's impact on stem form

A)

B)

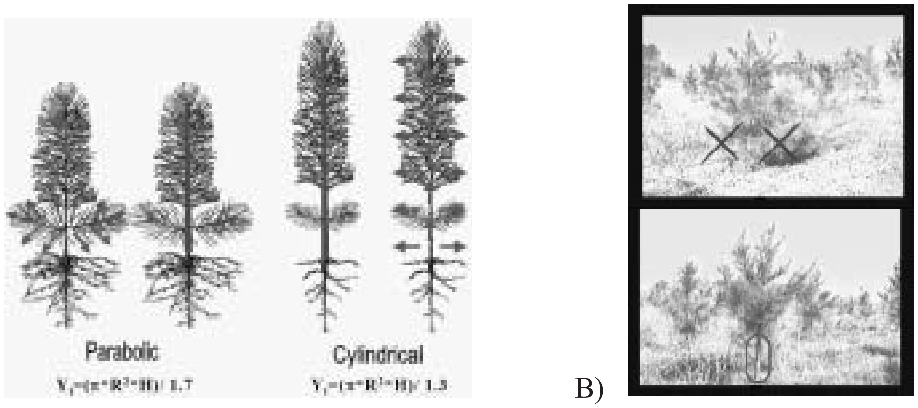
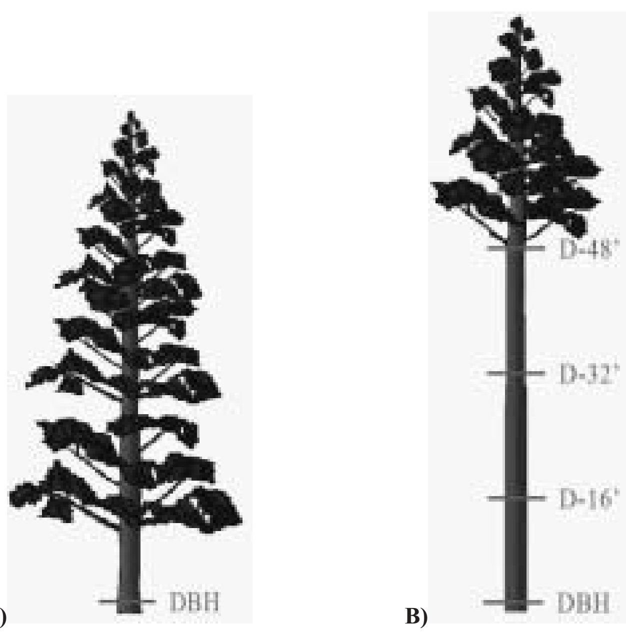


Figure 4—A) The parabolic stem form is shown with its allocation to increase lateral branching and stem taper and shorter spaces between branches versus decreased lateral branching and stem taper with greater spaces between branches. B) Indicates what early plantation tree form will look like when cultural practices in the nursery create bushes and retain low-lying branches (top) as opposed to the early abscission of lower branches with pole-shaped seedlings (bottom).

is presently observational. It was statistically shown, however, that desired diameters from 4 to 5 mm can be obtained with the 2-in sowing drum sown symmetrically at densities approaching 36/ft^2, and this could save tens of thousands of dollars when producing a few million stems. When diameters around 7 mm are desired, one can sow symmetrically with the 3-in sowing drum at densities approaching 25/ft^2 with minimal additional costs, but the asking price should be increased. However, what is the motive, the financial reward, for a nursery to employ innovative improvements like symmetrical sowing? Other innovations have yet to be fully tested (for example, increased clay content in sandy soils) that may also lower costs and increase stem and stand yield. Unfortunately, these trials may not be fully advanced unless seedling prices can better reflect the important aspects of stem quality ($/unit volume or $/unit weight), rather than basing them only on stem quantity.



A) B)

Figure 5—Bush versus pole at a late-stage plantation age. A) The bush-like stem form is raised on "passive" plantations, where nothing is done to eliminate low-lying lateral branches, and diameter at breast height is the only measurement required. B) The pole-like stem form is raised on a hypothetical high-density plantation, where "active" procedures remove lateral branches, and diameters at various log lengths are desired.

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Needs and Benefits of Nursery Accreditation

Robert P. Karrfalt

Robert P. Karrfalt is Director, USDA Forest Service National Tree Seed Laboratory, Purdue University, 195 Marstellar Drive, West Lafayette, IN 47907; telephone: 765.494.3607; e-mail: rkarrfalt@fs.fed.us

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Keywords: Agricultural Marketing Services, seedling certification, ISO, quality assurance

Introduction

It appears, from observations reported by both private and public nurseries, that there are nurseries that do not have adequate quality assurance procedures. Species are being mislabeled and incorrect seed sources are being sold. It appears that some nurseries have entered the market ill prepared to provide quality seedlings. On the other hand, why should anyone listen to an established nursery instead of a new nursery that is selling a less expensive seedling? Nursery accreditation would be one way for a reputable nursery trying to follow correct practices to distinguish themselves from those that do not. Accreditation may also assist in supporting claims a nursery wishes to make concerning its products. For example, a nursery may produce seedlings with a particular strain of mycorrhizal fungus. Accreditation is one method that can be used to certify that the mycorrhizal seedlings do, in fact, possess mycorrhizae. Another nursery may wish to certify that their products are developed and grown for use within a particular state or region while another may wish to certify for superior timber production.

Benefits to Nurseries

The first benefit of accreditation would be to raise overall industry quality. While established nursery programs are not having the problems mentioned earlier in regards to seed source, new players entering the market have been found to have problems. Therefore, there is a need to have a standard. A standard would help support established programs to continue good practices (keeping them in business) and serve to educate newly organized nursery businesses.

Secondly, there are immediate benefits to a nursery that accredits its program. Accreditation would encourage tighter management. If we know someone is going to look at what we do, we will do a more thorough job. This is simply human nature. Accreditation should also help achieve recognition within our own organizations that we have a quality program. This, in turn, can reasonably justify training for personnel as well as having good facilities. Accreditation can help focus on priorities; what gets counted gets done. Finally, the records required by an accreditation process will prepare a nursery to answer challenges to its work. Every nursery manager has to face customer complaints from time to time. A completely documented program from seed source identity to sowing through pack and ship will put the manager in position to answer objectively any questions raised from outside the nursery concerning seedling quality.

Aspects and Components of an Accreditation Program

The accreditation program would be strictly voluntary and open to any nursery or seed plant wishing to participate. No one would be prevented from selling seedlings from an unaccredited nursery or seeds from an unaccredited seed plant.

A participating nursery would need to prepare a standard operating procedures manual and a quality assurance manual. These can seem overwhelming at first look, but are simply a matter of saying what you will do, doing what you say, and proving you did it. These are more than bureaucratic exercises. They are excellent ways to maintain control of the nursery or seed plant and to instill pride in quality work among employees.

A participant would need to declare a scope of accreditation. Scope refers the area of expertise for the nursery. Perhaps the nursery would seek accreditation in growing bareroot longleaf pine seedlings, while another, mycorrhizal Virginia pine.

Accreditation Body

The accreditation body is the organization that reviews the manuals and conducts the audits and, finally, issues the accreditation. One possible accrediting body that could work for forest and conservation nurseries and seed plants is the Livestock and Seed (LS) Program, Audit, Review, and Compliance (ARC) Branch, Quality System Verification Program (QSVP), which uses ISO Guide 65 as a standard. This program provides voluntary conformity assessment and accreditation services to approved service providers to facilitate the marketing and distribution of agricultural products. The ARC Branch is an independent third party, and strives to provide services in accordance with accepted industry practices and internationally recognized guidelines. All services are provided on a cost-recovery basis with fees as nearly equal as possible to the actual cost of providing the service. The standards used are developed by the industry or sector of the industry. The USDA would not set the standards; the role of USDA is to meet the industry needs in a way that assists it to have credibility with the public.

Basic Steps to Accreditation

Application materials are prepared and submitted to the Agricultural Marketing Services (AMS) for review. After the AMS reviews and accepts the materials, an onsite audit is conducted. Upon passing the audit, the nursery's accreditation status is posted on the AMS, LS Program's Internet Web site. Official USDA shields, stamps, logos, or other marks may then be used on certified products, correspondence, advertising, and promotional material to signify that the nursery has been accredited for the claims it makes for its products. The accreditation is a means of marketing a good product, not a government inspection program.

References of AMS Accreditation Programs

ISO Guide 65—Requirements for bodies operating product certification systems.

ISO 19011:2002—Guidelines for quality and/or environmental management systems auditing.

ARC Instruction 1001—Process Verified Program.

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Acorn Size Effects Seedling Size at the Penn Nursery

Robert P. Karrfalt

Robert P. Karrfalt is Director, USDA Forest Service National Tree Seed Laboratory, Purdue University, 195 Marstellar Drive, West Lafayette, IN 47907; telephone: 765.494.3607; e-mail: rkarrfalt@fs.fed.us

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Keywords: *Quercus rubra*, *Quercus alba*, seedling grades

Introduction

The Pennsylvania Department of Conservation and Natural Resources Penn Nursery, located in Spring Mills, PA, was 1 of 4 nurseries participating in a study to determine the effect of acorn sizing on production of northern red oak (*Quercus rubra* L.) and white oak (*Q. alba* L.). It is hypothesized that larger acorns would produce larger seedlings. Therefore, by sizing acorns, it will be possible to produce more uniform beds of seedlings, tailor production schedules to acorn size, and reduce cull percentages.

Penn Nursery was the only nursery of the 4 involved in this series of experiments in which the white oak experiment was successfully carried out. The white oak survived poorly in the one other nursery where it was planted, as did the red oak in that same nursery. The results from the 2 nurseries where survival was good were reported previously (Karrfalt 2003). At the Penn Nursery, oak is a 2+0 crop. This prevented reporting the Penn results earlier with the results from the other 2 nurseries.

Materials and Methods

In the other surviving experiments (Karrfalt 2004), the root volume, fresh weight, diameter, and height of the seedlings were, on the average, all well correlated to the acorn size. Because all 4 seedling measurements were providing equal information on the relationship of seedling quality to acorn size, it was decided that only seedling height and diameter would be measured at the Penn Nursery. Seedling diameter and seedling height are the typical measurements used to evaluate seedling grades; therefore, these 2 measurements would have immediate translation for the current grading procedures. In addition, the red oak was top-clipped at the Penn Nursery, which precluded the measuring of seedling heights on that species.

One mixed lot of acorns for both red and white oak were sized by hand with round hole perforated metal screens arranged in a 2-full-size step series. The screen sizes used were 36, 38, 40, 42, 44, 46, 48, 50, 52, 54, and 56 for the red oak and 30, 32, 34, 36, 38 for the white oak. Each size fraction was mixed to assure uniformity.

Results

Figure 1 shows the regression line for plot means of seedling diameter against acorn size for the white oak. Figure 2 shows the same for seedling height. These plots demonstrate that, in general, the larger the acorn size, the larger the seedling for white oak in this crop. The regression for both seedling diameter and height against acorn size was highly significant. The relationship was greatly increased by simply dropping the 3 smallest plots from the 2 largest acorn sizes. With all the data, acorn size explained 21% of the variation in seedling diameter and, after dropping the 6 poorest performing plots, acorn size explained 56% of the variation.

Figure 3 shows the regression line for plot means against acorn size for red oak. This regression was not statistically significant. When dropping the lowest 3 plot values in all acorn sizes, the regression was significant, although acorn size still only explained 14% of the variation in seedling diameter.

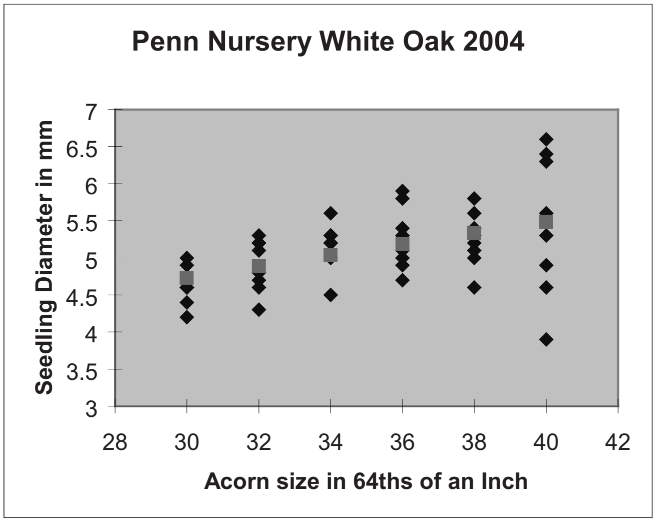

Figure 1—White oak seedling diameter plotted against acorn size as a function of screen openings.

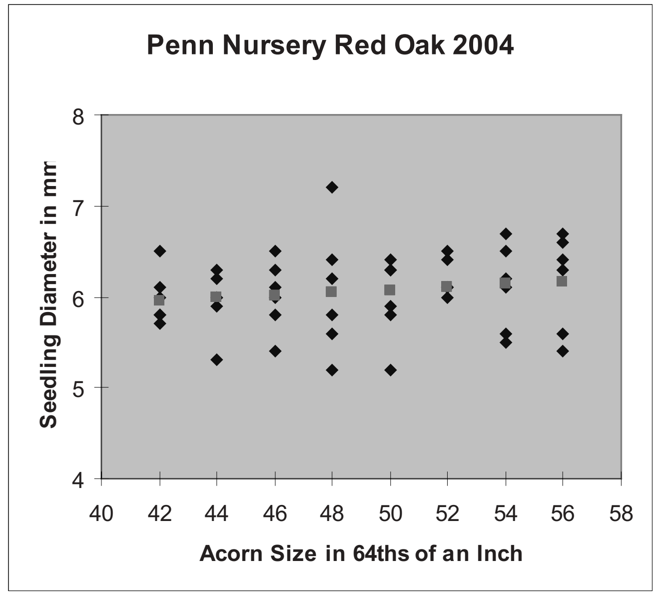

Figure 3—Red oak seedling diameter plotted against acorn size as a function of screen openings.

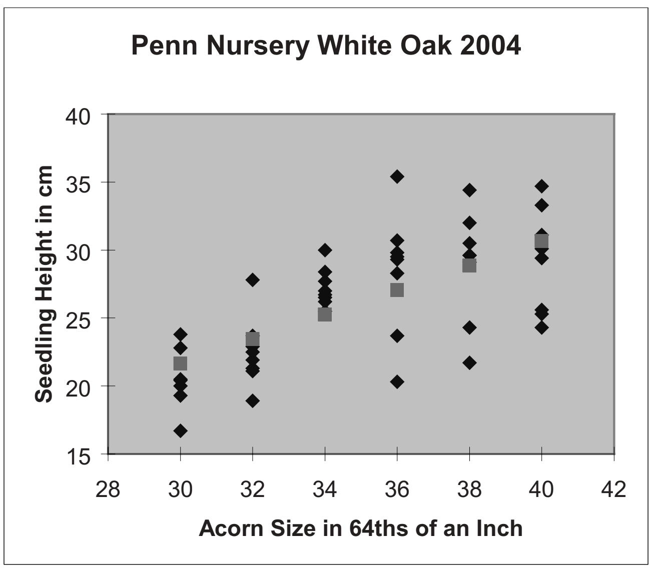

Figure 2—White oak seedling height plotted against acorn size as a function of screen openings.

Conclusions

The Penn Nursery experiment basically agrees with the results reported previously by Karrfalt (2003)—larger acorns will produce larger seedlings. The strength of the relationship was not as evident here, especially for red oak. The growing season at the Penn Nursery is approximately 90 days, and the soils are heavier and shallower than at the Indiana Department of Natural Resources Jasper-Pulaski Nursery and Wisconsin Department of Natural Resources Wilson Nursery reported in 2003. These more limited growing conditions could have limited the seedlings from expressing their full potential, which might have led to smaller differences in seedling size. Oak seedling size was influenced by acorn sizing at the Penn Nursery and is, therefore, one tool a nursery manager can use to manage the size of oak seedlings.

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Western Forest and Conservation Nursery Association Meeting

Medford, OR

July 26–29, 2004

Twenty Years of Nursery History—A Forest Service Perspective

Frank Burch

Frank Burch is in Silviculture Practices and Genetics, USDA Forest Service, Sidney R. Yates Federal Building, 201 - 14th Street SW, Washington, DC 20250; telephone: 202.205.0946; e-mail: fburch@fs.fed.us

In: Dumroese, R. K.; Riley, L. E.; Landis, T. D., tech. coords. 2005. National proceedings: Forest and Conservation Nursery Associations—2004; 2004 July 12–15; Charleston, NC; and 2004 July 26–29; Medford, OR. Proc. RMRS-P-35. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Keywords: National Forest Management Act, Healthy Forests Initiative, timber harvest

I was asked to speak to you concerning 20 years of nursery history from a Forest Service perspective. I hope you will allow me a little leeway here, because while I will focus on events of the past 2 decades, I find it necessary to begin by going a little further back in time.

Early Nursery History

I'd like to start in the waning years of the 19th century and briefly talk about 3 gentlemen who were instrumental in establishing the need for tree nurseries and who helped in defining key roles served by these facilities.

The first of these 3 people is Professor Charles E. Bessey. Dr. Bessey was the Professor of Botany and Horticulture at the University of Nebraska during this period. When he could break away from campus, he traveled widely, gathering tree, shrub, and grass specimens, and took a special interest in the Sandhills region. He discovered that the dry sandy soils in this region held significant moisture just a few inches below the soil surface. He also found that ponderosa pine (*Pinus ponderosa*) and red cedar (*Juniperus virginiana*) were present, but widely scattered in their distribution throughout the region. This led him to believe that it was possible to re-establish a forest in this sea of grass. Professor Bessey thus exemplifies the sort of intellectual curiosity and conviction that was instrumental in engaging others.

One of the people Professor Bessey influenced was Dr. Bernhard Fernow. Dr. Fernow was Head of the Division of Forestry in Washington DC in 1891 and was intrigued by Bessey's ideas; so intrigued that he worked out a deal. Dr. Fernow would provide the tree seedlings if Bessey would provide the land for the experimental plantation and plant the trees.

Now the seedlings that Dr. Fernow provided for this experiment were not exactly what we might call native plant materials. In this initial experimental plantation, Scots pine (*Pinus sylvestris*), Austrian pine (*P. nigra*), jack pine (*P. banksiana*), and Douglas-fir (*Pseudotsuga menziesii*) were planted in 4 quarter-acre plots. There are at least 2 versions to the story of what happened to that acre of land in the ensuing years. However, in either version, none of the seedlings Bessey and Fernow planted on that acre in 1891 survived a sustained drought experienced in the region in the 1930s.

The story of what happened to these seedlings is less important than the fact that this may well be the first example in this country of a jointly sponsored experiment between an academic institution and a Federal agency to apply the principles of forest ecology toward the re-establishment of tree seedlings. The zeal and enthusiasm that these 2 gentlemen applied to testing the hypothesis, and the fact that they worked in a close partnership to do so, are 2 key elements of the Forest Service nursery story.

At the very beginning of the 20th century, several other key players adopted this idea and applied their energies to the establishment of what was to become the Nebraska National Forest. I do not have time to recount who all of those players were, nor to do justice to their story. But their efforts won the support of President Theodore Roosevelt, who issued a proclamation creating 3 Forest Reserves in the Sandhills region. This momentum also led, in 1902, to the establishment of the first Forest Service nursery in the United States, named in honor of Dr. Charles E Bessey. Many in this room visited the Bessey Nursery in conjunction with a prior WFCNA meeting, so you know firsthand of the good work that continues to this day at this facility.

The adoption of Dr. Bessey's idea, and the extension of that idea toward the goal of managing the Forest Reserves, later to become the National Forests, for the "permanent good of the whole people," involved still other heroes of renewable resource management. Key among these is Gifford Pinchot, the first Chief of the USDA Forest Service, who, in 1947, called the Nebraska National Forest one of the great successful tree-planting projects in the world.

Pinchot's support was instrumental in the expansion of Forest Service nurseries. Pinchot helped to define a key role for the Forest Service nurseries in fostering the recovery of forest ecosystems following disturbance events. While the Bessey-Fernow experiment focused on afforestation, under Pinchot's leadership as the Agency's first Chief additional nurseries were established in those early days. The goals of these nurseries were to facilitate reforestation efforts following disturbance events such as large wildfires, to assure a continuous supply of wood fiber for domestic uses, to protect forest resources, and to protect the quality of water flowing off the National Forests. Pinchot's support also extended itself to conducting research to improve reforestation success on the National Forests. These manifestations of support at the very highest levels of the Agency, since its inception, cannot be underestimated.

Modern Nursery History

The concept of establishing Forest Service nurseries toward these aims was firmly rooted in legislation. This concept is supported in the Organic Act, and subsequent supporting language is contained in the Clark-McNary Act, the Knutson-Vandenberg Act, and other key legislation passed into law during the first half of the 20th century.

The second half of the 20th century saw increasing reliance on the National Forests for timber production. Timber production objectives for the National Forests were expressly provided for in legislation passed into law during this period, such as the Multiple-use Sustained Yield Act of 1966, the Resources Planning Act (RPA) of 1974, and the National Forest Management Act (NFMA) of 1976.

Timber harvest levels on the National Forests increased dramatically throughout much of the second half of the 20th century (Figure 1). Annual timber harvest levels immediately following WWII were below about 3 billion board feet nationally. During the period from 1950 through the mid-1960s, annual timber harvest rose sharply; by 1965, harvest levels were roughly 12 billion board feet per year nationally. Timber harvest levels in excess of about 10 billion board feet were sustained nationally in the period following the late 1960s through the early 1990s, with some oscillations occurring as a result of market-related factors.

So, as we focus today on the past 20 years, we see that it encompasses a period of precipitous change in terms of timber harvest outputs from National Forests. The first half of this 20-year period, from 1984 through about 1994, was a period of dramatic changes, with timber program levels declining from more than 12 billion board feet of harvest annually in the late 1980s to about 4 billion board feet per year in 1994. In the second half of this 20 year period, annual timber harvest levels have stayed below 4 billion board feet nationally, where they remain to this day.

Developments during the mid 1970s leading to the passage of NFMA of 1976 and the establishment of the Reforestation Trust Fund (RTF) in the mid-1980s also profoundly influenced these facilities. Through this statutory direction, Congress clearly expressed their intent to maintain forest lands in a forested condition by promptly reforesting National Forest System lands following harvest and other disturbance events. This led to accelerated reforestation programs in the late 1970s through the mid to late 1980s to eliminate a reforestation backlog of 3.1 million ac (1.3 million ha) first identified by the Forest Service in the mid 1970s.

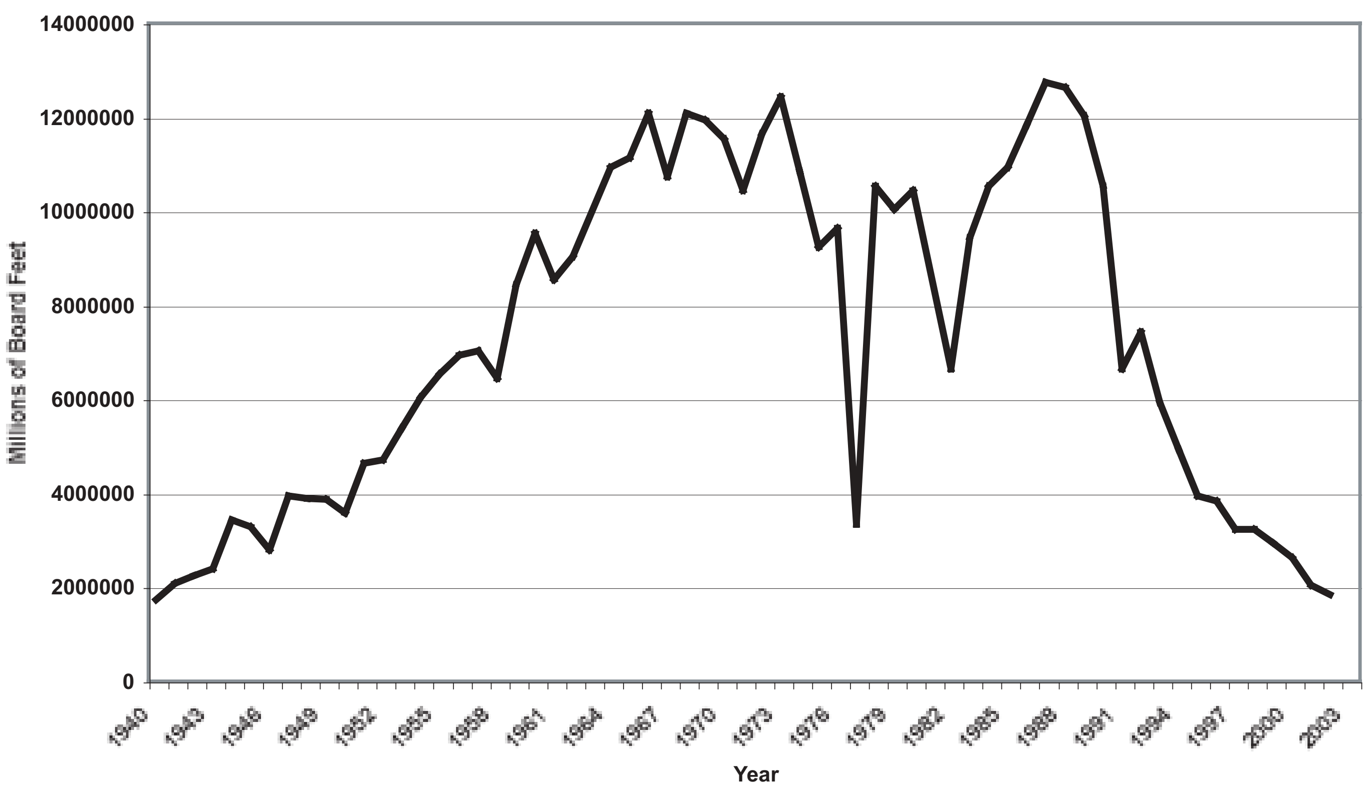

Figure 1—Annual timber harvest from National Forest system lands—service-wide totals.

Forest plans emerging following passage of RPA and NFMA also expressly identified the need for reforestation programs in support of planned timber harvest levels under these plans.

Forest Service Nursery System

The Forest Service Nursery System expanded in response to these influences during the second half of the 20th century until about the late 1980s. Table 1 lists the Forest Service nursery facilities in operation at the time of the first Service-wide Nursery Capacity study conducted by the Washington Office in 1979. As you can see, there are a total of 14 facilities listed on this figure.

You will also note that 6 of those 14 facilities remain in operation today. The key causal factors impacting both reforestation programs and Forest Service nurseries can be grouped into 4 general themes.

Policy Shifts

The first of these themes is policy shifts. In the early 1990s, the Agency embraced the concept of ecosystem management. This concept has led to a management framework whereby the National Forests are managed toward outcomes, rather than outputs. You are all familiar with these concepts so I won't dwell on them here. But this policy shift manifested itself in 2 important ways relative to Forest Service nurseries. First, the shift as announced by the Forest Service was explicitly tied to a targeted reduction in the practice of clearcutting on the National Forests, and the Agency has overachieved on the 70% reduction in this practice that was called for when the new policy was announced in June of 1992.

The policy shift also resulted in sharp reductions in timber harvest levels overall and impacted other regeneration harvest methods in addition to the clearcutting method. Timber harvesting practices on the National Forests shifted to favor intermediate harvest methods, such as thinning and salvage harvest methods.

This shift in harvest methods being applied on the National Forests continues to the present day. More recent initiatives, such as the Healthy Forests Initiative, continue to emphasize practices to reduce stand density and thereby promote health and fire-resiliency. This shift in emphasis has resulted in a decline in regeneration cutting on the National Forests.

Table 1—Forest Service Nursery System in 1979 and status in 2004.

Region	Nursery	Status in 2004
R-1	Coeur d'Alene, ID	In operation
R-2	CE Bessey, NE	In operation
	Mt Sopris, CO	Closed
R-3	Albuquerque, NM	Closed
R-4	Lucky Peak, ID	In operation
R-5	Placerville, CA	In operation
	Humboldt, CA	Closed
R-6	Bend, OR	Closed
	JH Stone, OR	In operation
	Wind River, WA	Closed
R-8	WW Ashe, MS	Closed
R-9	JW Toumey, MI	In operation
	Eveleth, MN	Closed
R-10	Petersburg, AK	Closed

Reduction in Land Base

The second major factor influencing reforestation programs and Forest Service nurseries is a sharp reduction in the land base available for vegetation management activities involving tree removals since the first round of forest planning was completed. Again, we are all aware of the changes that have manifested themselves in providing protections under the Endangered Species Act and as a result of the Roadless Rule as just 2 examples. Collectively, the forest plan decisions in recent years have resulted in significant downward adjustments in the land base being managed for purposes of timber production on many National Forests.

Decline in Funding

A third factor that is also highly significant to this story is the sharp decline in funding resources, particularly for tree planting operations on the National Forests. In the days when timber harvest levels were at their zenith, roughly two-thirds of the reforestation work on the National Forests was financed with Knutson-Vandenberg (K-V) deposits derived from the sale of National Forest timber. Today, less than one-half of the reforestation program is financed using these deposits. This has placed increasing pressure on scarce annual appropriations, and reforestation work must compete with other priority work (such as thinning to reduce the risks of catastrophic fires).

Forest Service Controls

In the USDA Forest Service, controls that once existed to accomplish reforestation work, such as line officer performance measures for reforestation success, have been replaced by measures that focus on other key priorities. This, too, has affected these programs. As management-guru Peter Drucker has said, "What gets measured gets done."

Forest Service Nursery Seedling Production

Figure 2 shows how these factors have affected tree seedling production at Forest Service nurseries over the past 20 years. In the first half of this period, these facilities produced in excess of 100 million seedlings annually. A period of steep declines in annual production levels occurred after fiscal year 1995, with production levels falling to about

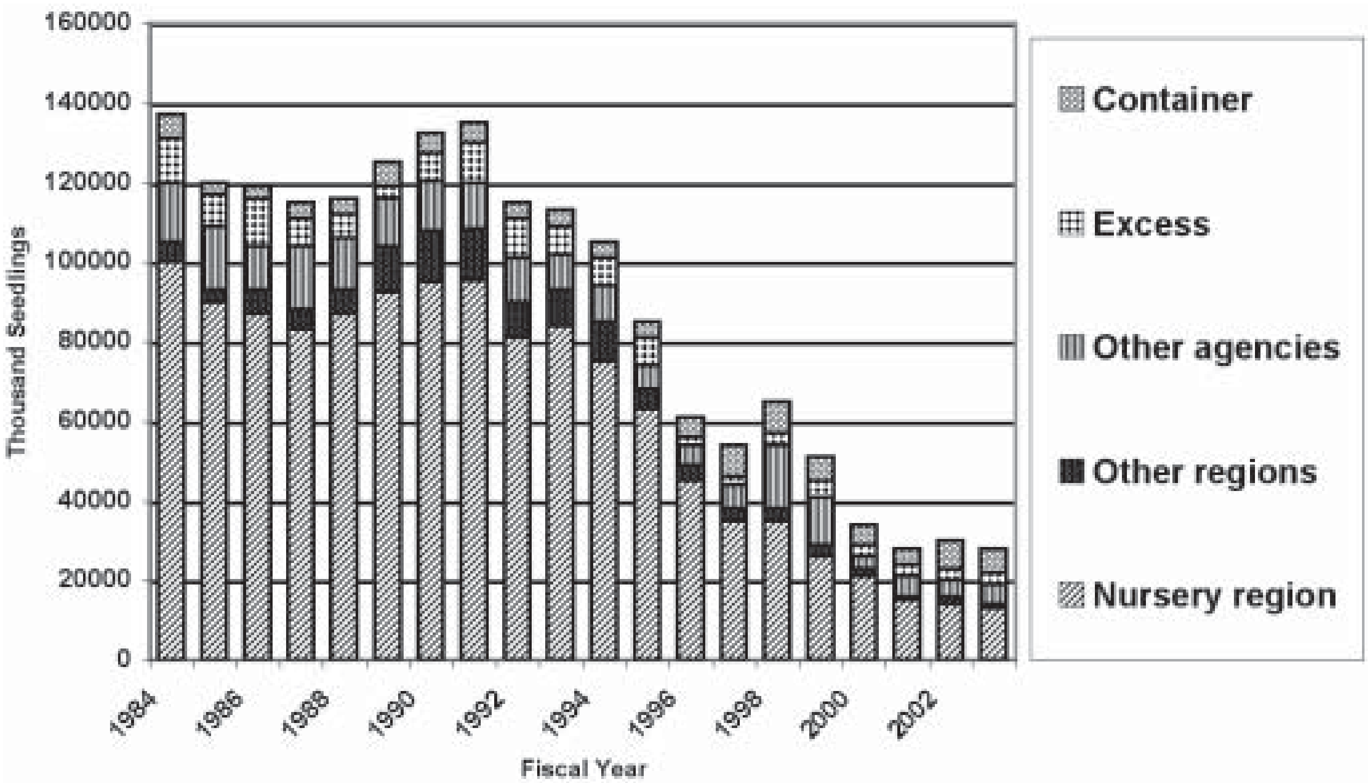

Figure 2—Trends in Forest Service nursery production.

30 million seedlings per year collectively at the 6 remaining Forest Service nurseries.

This decline in production has had a destabilizing effect on these facilities. Forest Service nurseries operate under the Working Capital Fund (WCF) concept. WCF operations must cover their operating costs using the revenues derived from the sale of seeds and seedlings produced at each facility. With declining seedling orders and constant or increasing fixed costs, the only remedy left for these facilities after they have done all they can do to promote the cost efficiency is to increase prices to cover costs.

Forest Service nurseries have been struggling with this dynamic for the past decade. Two national reviews conducted since 1996 have served to validate that the Agency continues to need and value these facilities, but we have struggled to find enduring solutions that can be embraced by Agency decisionmakers to provide for the continued financial health of our nurseries.

We value these facilities because they continue to fulfill key roles that initially led to their establishment. These facilities continue to be a reliable source of locally adapted, high-quality plant materials for use in forest restoration projects. We value these facilities because, consistent with their 100-plus year heritage, our nursery managers continue to apply their expertise to testing and demonstrating plant propagation and production methods and to freely share their results with other growers. They provide technical advice and assistance to their customers, which is made even more important with the attrition in skills resulting from retirements and workforce reductions on most National Forest units. We value these facilities for the important role they serve in public education and communicating the importance of conserving and renewing forest resources. We value them in their role as partners with the practitioners attending this meeting.

Conclusions

As we near our 100th year as an Agency within the Department of Agriculture, a look to the past might well inform our future. On our present course, the strategic objectives of recent Agency initiatives to promote the health and resiliency of forested ecosystems will provide opportunities. The need to foster recovery following natural disturbance events is prominent in each of these initiatives. There are clear roles for vegetation management, and for Forest Service nurseries in pursuing these goals.

To make good on these goals will require the grass-roots zeal exhibited by people like Dr. Charles E. Bessey when he dreamed of establishing a forest in the Sandhills region. It will require the skill and expertise of people like Dr. Bernard Fernow to champion the cause, marshal resources and support to do make it happen, and oversee the work to ensure that it is done properly. Most importantly, it will involve leadership from line officers throughout the Agency akin to the example set by Gifford Pinchot a century ago.

It is my sincere hope that my successor will be able to report favorably in each of these areas when revisiting this subject at the 2024 Western Forest and Nursery Conservation Association meeting.

Retractable Roof Greenhouses and Shadehouses

John W. Bartok, Jr.

John W. Bartok, Jr., is Extension Professor Emeritus and Agricultural Engineer, Natural Resources Management & Engineering Department, University of Connecticut, Storrs, CT 06269-4087; telephone: 203.486.2840; e-mail:jbartok@rcn.com

In: Dumroese, R. K.; Riley, L. E.; Landis, T. D., tech. coords. 2005. National proceedings: Forest and Conservation Nursery Associations—2004; 2004 July 12–15; Charleston, NC; and 2004 July 26–29; Medford, OR. Proc. RMRS-P-35. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Keywords: open-roof greenhouse, roll-up roof greenhouse, folding roof greenhouse, lath house, high tunnel, ventilation, energy conservation

Greenhouse Structures

Open-roof greenhouses provide a natural environment for plant growth when the outdoor weather is suitable and an artificial environment when it is too hot or cold. Opening the roof over the plants increases light intensity, which can help to control the growth habit, flowering, and crop timing. It also reduces electricity costs because expensive fan cooling is not needed.

Roll-Up Roof

Several methods are used to open the roof. Some manufacturers make a roof that opens by rolling up the single or double layer of flexible plastic glazing that runs the length of the greenhouse bay. A small gear motor rotates a shaft that winds the plastic onto it like a window shade. A light, second framework over the structure secures the plastic from bellowing out during windy weather. Opening and closing the roof can be either manual or automatic. Each side of the roof can be controlled independently for flexibility in cooling.

Folding Roof

Folding roof greenhouses work well in snowy climates, as they can be tightly closed during cold weather. Most designs use standard vent hardware. Some have panels that hinge at the gutter and open upward. Opening is almost 100%. Others have panels that are hinged at the ridge and one gutter, and slide sideways on teflon bearings. Opening is about 85%. Most designs use rubber gasketing to seal the joints. Glazing can be glass, polycarbonate, or film plastic. Some manufacturers provide a movable gutter to collect rainwater when the roof is partially open. Wind sensors should be installed to close the roof in stormy weather. Movable shade is frequently installed with the open roof design. It reduces the heat load by reflecting the sun's rays back out. The shade curtain should be of a porous design to allow heat to escape. In northern climates, an energy blanket may also be installed to reduce heat loss during the winter.

Retractable Roof

These structures consist of a steel frame, flexible glazing, and cable support. Woven UV stabilized polyethylene film creates a watertight glazing. Depending on the cropping system, bracing of the structure can be external cables attached to deadmen, internal compression braces, or trusses with cable X-bracing. Flat roof designs are used where there is little rain or snow. A-roof designs shed the rain and snow to an internal gutter system. Designs that will carry up to 35 lb/ft^2 (170 kg/m^2) snow load and 100 mph (160 kph) wind loads are available. The roof opens in sections by moving the leading edge of the curtain. One gear motor will handle up to 50,000 ft^2 (4,650 m^2) of roof. Heating is more difficult than in a conventional greenhouse due to the single layer plastic and greater infiltration through gaps and cracks in the seals.

High Tunnel

These low-cost, unheated poly-covered hoophouses can extend the growing season or provide overwinter protection to plants. A couple of manufacturers make a gutter-connected model. Ventilation is manual, by rolling up the sides, opening the doors or, in the case of the gutter-connected design, pushing up the roof plastic. Cost is usually less than U.S. $1/ft^2$ (U.S. $11/m^2$).

Basic Principles of Natural Ventilation

Retractable roof designs can provide better dormancy maintenance, plant hardening, and insect screening through ventilation control. Natural ventilation systems operate on the principle that heat is removed by a pressure difference created by wind and temperature gradients. Wind plays the major role. For a well designed greenhouse, wind speeds of 1 mph (2 kph) are adequate to keep the inside temperature within 2 °F (1 °C) of outdoor ambient. Weather records show that there are very few days that the wind is less than 1 mph (2 kph), especially if the outdoor temperature is above 80 °F (27 °C).

Buoyancy, the effect from heated air getting lighter and rising, also aids ventilation. The trend toward taller greenhouses has helped this in that it gets the hot air higher above the plants. The standard gutter height is now 12 ft (3.5 m), and taller greenhouses are used for some crops.

Natural-cooled greenhouses provide more uniform temperature throughout the greenhouse as compared to fan cooling where the temperature between the intake louvers and fans may be as much as 15 °F (8 °C). Natural ventilation systems also reduce energy costs by eliminating the 0.5 to 1 kilowatt-hour/ft^2/year of electricity needed to operate a fan system. In snow country, installing small fans with a capacity of 1 to 2 cfm/ft^2 of floor area will allow ventilation when there is snow in the gutters and the roof cannot be opened.

Shadehouses

Shade structures are used to provide protection against wind and solar radiation. They are a useful tool for modifying the environment and extending the growing season, both in cold and warm weather.

In nursery operations, a shadehouse can provide temperature and weather protection year-round. It can also reduce irrigation needs during the summer. In some areas, the reduction in animal damage will help to pay for the structure.

Why Shading?

Incoming solar energy is converted to heat energy when it strikes plant leaves. This can result in excessive air, leaf, and soil temperatures. Placing plants under 30 to 50% shade in the middle of the summer can lower leaf temperature by 10 °F (6 °C) or more. This, along with reduced wind speeds, can significantly reduce transpirational water losses during the growing season.

Not all plants require full sunlight to grow. Most plants can only utilize a limited amount of light, called the light saturation level. African violets lose chlorophyll at an intensity of 1,500 foot-candles (ft-c) (16,100 m-c). Foliage plants may be burned at a level over 2,000 ft-c (21,500 m-c). Red oak (*Quercus rubra*) and Douglas-fir (*Pseudotsuga menziesii*) have a saturation level of about 3,000 ft-c (32,300 m-c). Chrysanthemum and geranium plants will take around 4,000 ft-c (43,000 m-c). Rose and carnation plants will take full summer light intensity of up to 10,000 ft-c (107,600 m-c). The science of shading is really an art as the level of light that you allow to reach the top of the plant is reduced significantly by the time it reaches the bottom leaves.

Lath Houses

The original shadehouses were called lath houses, as they were frame structures covered with wood lath. Most were made with poles set into the ground with 2-in (5-cm) framing lumber nailed to the poles to support the lath. A 50% shade was created by leaving a space equal to the width of a lath between adjacent laths.

When woven polypropylene was first introduced to the greenhouse industry, shadehouses took on a new appearance. Wire or cable was adequate to support the lightweight material. Today, most shade structures are covered with either polypropylene, polyethylene, polyester, or a composite fabric which usually contains aluminized polyester strips.

Most greenhouse manufacturers can supply a shadehouse. They can be either fixed-roof or retractable-roof design. Fixed-roof designs are either rigid frame or cable frame.

Cable Frame Shadehouses

The cable frame shadehouse probably evolved from the shade tobacco industry where several thousand acres are covered annually in Connecticut and other states to modify the environment to produce tender tobacco leaves for the wrapper of the best quality cigars. Posts surrounded by concrete are set into the ground on an approximate 20 ft by 20 ft (6 m by 6 m) spacing. Height can be 8 ft to 16 ft (2.5 to 5 m). Deadmen located around the perimeter provide the bracing for the tension in the wires. Stainless steel cable with adjustable turnbuckles are strung between the posts to support the cloth shade material. In the tobacco shadehouses, the edges of the material are sewn around the wires with a strong thread. In the nursery shadehouses, clips or hooks are used. Shade material hung on the sidewall around the perimeter is attached to the upper wire and usually buried in the soil. It provides wind protection to the plants. Due to the variables in construction, cable shadehouses usually do not carry a design wind or snow load.

Rigid Frame Shadehouses

In rigid frame shadehouses, the cable is replaced by pipe or rollformed truss members. This supports the shade cloth. Instead of deadmen, diagonal knee braces, both horizontal and vertical, create the rigid frame. Post spacing is less than with the cable system, usually 10 to 18 ft (3 to 5.5 m). Shade material can be attached with tek screws or clips.

Retractable Roof Shadehouses

Retractable roof shadehouses use the same technology as that used in greenhouses. They are available from several manufacturers in several widths. They can have either cable or truss supports, and usually carry a design wind load.

As solar radiation varies considerably over the day and from season to season, the main advantage of the retractable design is the ability to regulate the amount of sunlight that reaches the plants. Increased plant growth results as ventilation can be controlled to reduce temperature. Ventilation can also reduce disease incidence. Reducing the intensity of sunlight can lower irrigation needs as plants and soil are kept cooler.

Both cable and truss style retractable roof designs utilize standard energy blanket technology for opening and closing the shade. One gear motor can handle up to 50,000 ft^2 (4,650 m^2) of growing area. The shade material is usually stored at the post line. For areas that receive considerable snowfall, the roof is retracted and snow is allowed to cover the plants, providing insulation. The shade material is stored under a protective hood so that it doesn't get covered with snow.

For a grower that is now utilizing the conventional 14 ft (4 m) wide overwintering hoophouse covered with white poly for protection of perennials, herbs, and nursery stock, a retractable roof structure can give better temperature control. It can also reduce plant handling cost, as the larger area under one roof and the vertical sides allow the use of mechanized handling equipment.

Sidewall and Endwall Ventilation

In most greenhouses and shadehouses, it is advantageous to have sidewall ventilation. First, it can be used as a first stage of cooling. Second, in larger structures, it can supply most of the intake air and the roof vents act as the outlet.

Sidewall and endwall covering can be fixed poly, roll-up curtains, or rigid polycarbonate.

Manual and motorized rollup systems are available. These use a conventional roll-up mechanism and small gear motor. Ventilation rate is controlled by the size of the opening. The drop-down system works better in cooler weather as the air is introduced above the plants. Restraining cables or guides are installed to keep the detached sidewall curtain from blowing on windy days.

Plant Nutrient Testing and Analysis in Forest and Conservation Nurseries

Thomas D. Landis
Diane L. Haase
R. Kasten Dumroese

Thomas D. Landis is Consultant, Native Plant Nursery Consulting, 3248 Sycamore Way, Medford, OR 97504; telephone: 541.858.6166; e-mail: nurseries@aol.com. Diane L. Haase is Associate Director, Nursery Technology Cooperative, Department of Forest Science, Oregon State University, 321 Richardson Hall, Corvallis, OR 97331; telephone: 541.737.6576; e-mail: diane.haase@oregonstate.edu. R. Kasten Dumroese is Research Plant Physiologist with the USDA Forest Service, Southern Research Station, 1221 South Main Street, Moscow, ID 83843; telephone: 208.883.2324; e-mail: kdumroese@fs.fed.us

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Abstract: Supplying mineral nutrients at the proper rate and in the proper balance has a major effect on seedling growth rate but, more importantly, on seedling quality. In addition, mounting concerns about fertilizer pollution are increasing awareness of the benefits of precision fertilization. Because they reflect actual mineral nutrient uptake, plant tissue tests are the best way to monitor a fertilization program. Analytical laboratories are able to accurately and precisely measure the levels of all 13 mineral nutrients in a small sample of plant tissue, and nursery managers can obtain results in as little as a week. While tentative guidelines for analyzing mineral nutrient levels exist, they are for general classes such as "conifer seedlings" and are of limited usefulness for precision monitoring of fertilizer programs. Most published test results are for commercial tree species, and almost nothing is known about other native plant species. Government nurseries can provide a real service by sharing their test results with other nurseries, and nursery cooperatives can serve as clearing houses for plant nutrient test results.

Keywords: nutrient content, nutrient concentration, nutrient deficiency

Introduction

For those working in forest and conservation nurseries, reforestation, or restoration, there is a logical connection between the mineral nutrient content of seedlings and their quality. Tree seedlings and other native plants use the 13 essential mineral nutrients for growth and development. While some mineral nutrients may become limiting in natural settings, nursery managers are able to supply nutrients through fertilization for optimal seedling growth. Nurseries, therefore, should be able to produce high quality seedlings that contain optimum levels of mineral nutrients when delivered for outplanting.

The purpose of this paper is twofold. First, we present an update on terminology and technology of plant nutrient testing and analysis. Second, we discuss how nursery managers can use results of these tests to produce the highest quality seedlings in forest and conservation nurseries. Foresters and restorationists will also be able to use this information when evaluating the quality of their nursery stock.

Basic Concepts of Mineral Nutrition for Nursery Seedlings

More than half the elements in the periodic table have been found in plant tissue (Kramer and Kozlowski 1979) because most chemical ions in the soil solution are passively absorbed in the large volume of water that is absorbed during transpirational uptake. However, only 16 elements have been proven to be required for plant growth. A mineral nutrient must meet 2 criteria if it is to be considered essential for plant growth. First, it must be required for the plant to complete its life cycle; and second, it must be part of some plant constituent or metabolite (Epstein 1972). Of these 16 essential nutrients, carbon, hydrogen, and oxygen are obtained from water and carbon dioxide and together account for approximately 96% of the dry weight of plant tissue. The remaining 13 elements are of mineral origin, being absorbed as ions from the soil. These elements have been divided into 6 macronutrients and 7 micronutrients based on relative concentration (Table 1).

The functions of mineral elements vary from the structural components of plant cells to the physiological actions of molecules such as enzymes. All macronutrients, with the exception of potassium, are incorporated into cellular constituents (for example, nitrogen and magnesium in the chlorophyll molecule) but may also serve physiological functions as coenzymes or enzyme activators. Micronutrients primarily serve in a variety of metabolic functions in cells but do not constitute a significant part of any structural component.

Mineral Nutrient Uptake Patterns

The relationship between mineral nutrient uptake and plant growth follows a characteristic pattern (Figure 1). When a nutrient is present in relatively low concentrations in plant tissue, it is considered deficient and limiting to plant growth. At the lower ranges of this deficiency, the plant often exhibits certain observable characteristics, and these deficiency symptoms can be helpful in diagnosis of the deficiency. At slightly higher concentrations, however, the deficient nutrient is still low enough to limit plant growth but not low enough to produce deficiency symptoms. This condition is called "hidden hunger" because it is difficult to visually diagnose.

When supply of the nutrient is no longer limiting to growth, the plant growth rate increases rapidly until the critical point is reached (A in Figure 1). The critical point is the tissue nutrient concentration at which the growth rate declines significantly and is usually defined as 95% of the maximum growth or yield. The range of nutrient concentration at which maximum growth occurs has been defined as the optimum range. Plants may continue to take

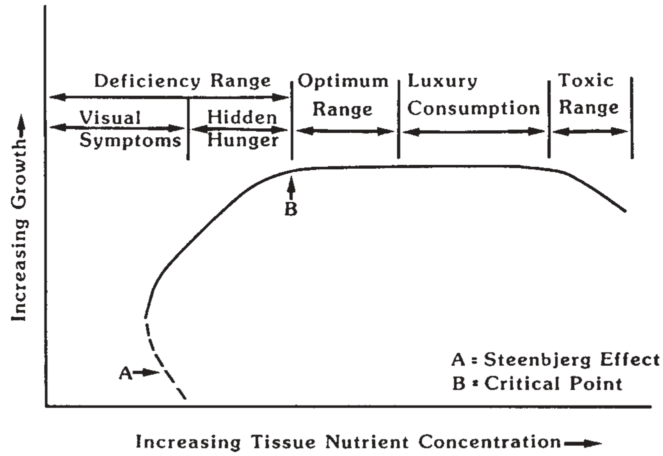

Figure 1—Hypothetical relationship between mineral nutrient concentration in seedling tissue and growth (modified from Chapman 1967).

up mineral nutrients even though this additional uptake does not result in more growth (luxury consumption). When tissue nutrient concentrations reach extremely high levels, toxicity can occur with certain elements because plant growth begins to decrease with additional amounts of nutrient (B in Figure 1).

Plant Nutrient Analysis Methodology

Sample Collection and Handling

Correct interpretations of nutrient test results cannot be made unless proper sampling methods have been used. Samples submitted for plant nutrient analyses should be collected in a consistent manner for optimum data quality. For example, the age of the tissue can have a significant

Table 1—Standard range of values for mineral nutrient concentrations in conifer needle tissue of container and bareroot nursery stock (Landis 1985).

Nutrient	Symbol	Adequate range		Mobility in plant tissue
		Bareroot	Container	
Macronutrients as percent				
Nitrogen	N	1.20 to 2.00	1.30 to 3.50	Mobile
Phosphorus	P	0.10 to 0.20	0.20 to 0.60	Mobile
Potassium	K	0.30 to 0.80	0.70 to 2.50	Mobile
Calcium	Ca	0.20 to 0.50	0.30 to 1.00	Immobile
Magnesium	Mg	0.10 to 0.15	0.10 to 0.30	Mobile
Sulfur	S	0.10 to 0.20	0.10 to 0.20	Mobile
Micronutrients as ppm				
Iron	Fe	50 to 100	40 to 200	Immobile
Manganese	Mn	100 to 5,000	100 to 250	Immobile
Zinc	Zn	10 to 125	30 to 150	Immobile
Copper	Cu	4 to 12	4 to 20	Immobile
Boron	B	10 to 100	20 to 100	Immobile
Molybdenum	Mo	0.05 to 0.25	0.25 to 5.00	Immobile
Chloride	Cl	10 to 3,000	10 to 3,000	Mobile

influence on nutrient levels. Mobile nutrients are often found in higher concentrations in the younger, actively growing foliage, whereas immobile nutrients tend to concentrate in older parts of the plant (Table 1). Therefore, it is imperative to select tissue so that variation due to age is minimized. This can be done by sampling the entire plant in young non-woody seedlings, or by sampling the oldest or newest foliar tissue in older plants. Usually, nurseries tend to look at total foliar nutrition or at the tissue that has most recently matured. Analyses of older tissue are useful for diagnosing problems associated with immobile elements, especially micronutrients such as boron (Table 1).

The best type of tissue sample will also depend on whether you want to measure nutrient concentration or content. Because nutrient concentration is a proportional measure, either foliage or whole plants may be used. Nutrient content, however, is reported as weight per plant. Therefore, it is necessary to know the over-dry weight of the sample.

Sampling intensity is another important factor to consider. Too often, a nursery will send just one composite sample for analyses once or twice a year; these do not accurately assess crop nutrition. For example, if seedlings with a deficiency problem are combined with seedlings that do not have a deficiency, then the true problem will be diluted in the composite sample. While the nursery manager may be pleased to save money on laboratory analyses, what has really happened is that the money was wasted on meaningless data. Management decisions based on conclusions made from such data can be risky and costly.

The frequency of taking samples will also be influenced by the crop's growing cycle and the nursery's cultural practices. It is best to sample at several times during the growing season rather than to focus on samples taken at one time only. Regular, replicated sampling on randomly selected representative seedlings results in credible information, which can be confidently used for monitoring seedling nutrition.

Laboratory Analysis Methods and Costs

Most laboratories use standard methodology to assess plant tissue. In general, foliar tissue is digested to remove the carbon component and then examined with inductively coupled plasma emission spectrometry (ICP) to determine concentrations of individual nutrients. For a better understanding of ICP and the other analytical procedures used by laboratories, the reader is referred to Mills and Jones (1996).

Reporting Units

Most analytical labs report their results in concentration units, although nutrient content is often reported in research studies. For day-to-day nursery work, concentration units are the most common.

Concentration—Plant nutrient levels are traditionally reported in proportional units of tissue dry weight: macronutrients in percent and micronutrients in parts per million (ppm). Proportional units describe how concentrated the nutrients are in the tissue. Conversion between percent and ppm is sometimes necessary and is very simple. To convert percent to ppm, multiply by 10,000. To convert ppm to %, divide by 10,000.

You may see published concentration units using the international standard (SI) of grams per kilogram (g/kg) for macronutrients. To convert from SI units to percent, just divide by 10. The SI units for micronutrients are milligrams per kilogram (mg/kg), which is the same as parts per million. Another unit of nutrient concentration is micrograms per gram (μg/g), which is the same as ppm.

Content—Content is the actual amount (g or mg) of a nutrient in a given amount of plant tissue (for example, total foliage or 100 needles). This is calculated by multiplying tissue dry weight by concentration. Although this measure requires additional effort to attain, it can yield useful information. When nutrients are diluted in rapidly growing seedlings, content can provide useful information about the plant's nutrient status that is not apparent in nutrient concentration data. Nutrient content can also allow data interpretation via vector analysis (Haase and Rose 1995) and is usual for comparisons among seedlings in fertilization studies where treatments cause seedlings to be different sizes.

It is important to carefully distinguish between nutrient concentration and nutrient content when comparing data. The terms are often confused in the literature, which has confounded interpretation. Both concentration and content units have limitations. Data reported in concentration units are subject to the dilution effect resulting from new growth; data reported in content units vary by plant size.

Variation Between Laboratories

Laboratory analyses can vary within and between labs, as well as costs, and turnaround times (Table 2). In a study conducted by the Oregon State Nursery Technology Cooperative (NTC), identical tissue samples were sent to several labs. The resulting data revealed notable variation. So, it is advisable for a nursery to investigate a lab's reputation prior to submitting samples and to consult other local nurseries about their experiences. Once a lab has been selected, it is crucial to stick with that lab throughout the season (and even for many years) in order to generate data that is not influenced by lab-to-lab variation. Furthermore, it is a good idea to "test" the lab by including identical samples every now and then.

Table 2—Analytical costs and turnaround times from laboratories used by Western nurseries.

Laboratory and location	Complete plant tissue analysis	Turnaround time[a]
	U.S. $	*days*
JR Peters (PA)	36	10
Quality Analytical (FL)	25	7
A & L Western (OR)	26	10
Micro Macro (GA)	30	7
Soil & Plant (CA)	50	21
MDS Harris (NE)	16 to 30	7

[a]Web site or e-mail service is necessary for the shortest times.

Interpreting Plant Nutrient Test Results

Most of us have struggled over laboratory reports of seedling nutrient analyses and attempted to make some sense out of them by comparing the reported nutrient values to ranges of values published in some nursery manual. The interpretation of seedling nutrient analyses requires an appreciation of the variation that can be expected. Skill in interpretation is only acquired through practice and experience, and so professional help should be sought when considering nutrient analysis for the first time.

Types of Variation in Plant Nutrient Data

Genetic: Genus, Species, or Ecotype—Plant nutrient test results have been shown to vary between different species or even between different ecotypes of the same species—interior and coastal Douglas-fir (*Pseudotsuga menziesii*) (van den Driessche 1984b). Research trials using controlled fertilizer solutions in sand cultures have shown that even closely related plant species take up mineral nutrients at different concentrations—for example, sugar maple (*Acer saccharum*) and red maple (*Acer rubrum*). Some species, such as balsam poplar (*Populus balsamifera*), are very efficient at nutrient uptake and are able to accumulate very high levels of most macronutrients when compared to normal ranges (Table 3).

Seasonal: Changes During Growing Season—The amount of mineral nutrients in plant tissue can change dramatically during the growing season, primarily due to the growth dilution effect. Tests taken throughout the season show that nutrient levels are high early in the year when plants are small, but decrease steadily as the growth rate increases.

Between Nurseries—Nursery environment may also affect the nutrient status of tree seedlings because of differences in soil fertility, cultural practices, and climate. In a study of Douglas-fir seedlings, both macro- and micronutrients were shown to vary not only between nurseries but between sections in the same nursery (Krueger 1967). In an NTC study, nutrients of healthy Douglas-fir seedlings were monitored regularly at 3 nurseries for 1 growing season. Results showed considerable variation between the nurseries as well as seasonally (Nursery Technology Cooperative 2004).

Stock Type: Bareroot Versus Container—The same species of plant will typically show much higher levels of mineral nutrients when grown in container nurseries compared to those grown at bareroot facilities. As shown in Table 1, container nursery stock have higher ranges for almost all nutrients. Container stock is grown in individual containers so that competition between seedlings is lacking. More importantly, artificial growing media have very high cation exchange capacities, and mineral nutrients are not chemically fixed like they are in many field soils. This is particularly true for micronutrients, like iron. As a result, the width of recommended nutrient ranges must be necessarily broad for bareroot stock due to soil variations. Because of the uniformity of commercial growing media, however, it should be possible to develop narrower guidelines for container seedlings.

Comparison to Standard Values

For plant nutrient values to be meaningful, they must be compared to some ideal or “standard” values. Most sources present standard nutrient values as ranges instead of discrete values to accommodate natural variation. Nutrient standards for conifer foliage tissue are presented in Table 1. The problem with these “generic” nutrient standards is that they may not be sensitive enough to reveal significant differences. Until more specific data can be accumulated, however, these general nutrient standards are the best available. Some nurseries are beginning to gather specific mineral nutrient values for their species and environments. Loblolly pine seedlings were collected from 33 Southeastern United States nurseries by the Auburn Nursery Cooperative and analyzed at the same laboratory for seedling nutrients to provide base data for soil management decisions (Boyer and South 1984). Likewise, the NTC at Oregon State University monitored bareroot seedling nutrition from 3 nurseries to determine expected ranges for Pacific Northwest Douglas-fir seedlings with target morphological characteristics (Nursery Technology Cooperative 2004).

Ideal values are provided for bareroot commercial conifers in the Pacific Northwest (Krueger 1967; van den Driessche 1984a; Youngberg 1984) and some hardwood species from the Northeastern States (Erdmann and others 1979). Unfortunately, some very good information has been published in rather obscure nursery proceedings and is not accessible to most nurseries (for example, Hallett 1985). Be wary of plant nutrient results in general horticultural publications. For

Table 3—Mineral nutrients can vary considerably between plant species or even within a genus.

Mineral nutrient	Sugar maple[a]	Red maple[a]	Paper birch[a]	Balsam poplar[b]
	percent			
Nitrogen	2.24	1.43	1.12	3.44
Phosphorus	0.16	0.17	0.51	0.35
Potassium	0.90	0.78	1.46	2.71
Calcium	2.38	2.24	1.87	0.99
Magnesium	0.43	0.63	1.17	0.33
Sulfur	0.19	0.21	0.22	0.48

[a]Grown in same fertilizer solution (Erdmann and others 1979).
[b]Grown at low nitrogen rate of 50 ppm (Wood 2004).

example, Mills and Jones (1996) report nutrient data for a wide variety of plants including sections on conifers and forest trees. However, many of these are from cultivars and the season of collection is simply listed as "summer."

Unfortunately, published mineral nutrient values for most native plant species just don't exist. Native plant nurseries are doing plant tissue analysis, but do not share their results. Although many laboratories provide recommended general mineral nutrient ranges with their test results, they do not have experience with minor crops like most native plants. Also, it is important to be aware that general guidelines are typically based on values at the end of the year after growth has stopped and so are of little value during the growing season. Therefore, the best and most useful data must be developed on a nursery by nursery basis. By using the same laboratory season after season, nurseries can quickly generate enough data to develop reasonable guidelines.

Mathematical Analysis

Several different types of mathematical analysis have been published. Ingestad (1979) recommended using nutrient ratios as a way to compare the levels of different nutrients. The Diagnosis and Recommendation Integrated System (DRIS) technique has been advocated for agronomic crops (Mills and Jones 1996). Vector analysis has been used to examine nutrient concentration, nutrient content, and plant dry weight in an integrated graphical format (Haase and Rose 1995). These types of mathematical analysis are rarely used in operational nurseries. For those interested in a comprehensive explanation of the various techniques, the authors recommend Bigg and Schalau (1990).

Uses of Plant Nutrient Analyses

Testing nursery plants for nutrient concentration can have several practical applications: adjusting fertilization, comparing growth curves, diagnosing nutritional problems, establishing seedling quality, and resulting outplanting performance.

Adjusting Fertilization

Using plant nutrient analysis to establish and adjust fertilization schedules is the most common application in forest and conservation nurseries. Determining the type and amount of fertilizer to apply and the proper application times can be bewildering to the novice grower. Even for the experienced nursery manager, the concentration of essential mineral nutrients in seedling tissue is the best way to determine the effectiveness of a fertilization program.

Compare to Seedling Growth Curves or Fertilizer Data—Collecting and analyzing seedling samples at regular intervals during the growing season and comparing the results to growth curves or correlating them with fertilization trials can be a powerful management tool. Accumulating test results in a spreadsheet program along with seedling growth data allows easy analysis and creates a permanent database that only gets better with time. When growth versus nutrient curves are developed, it is easy to identify the critical point in the curve when growth begins to flatten out (Figure 2A). Applying more fertilizer will only lead to luxury consumption and, in the case of nitrogen and phosphorus, may cause environmental pollution. Be sure to consider the lag time between fertilizer application and uptake. In bareroot nurseries, this can take 2 to 4 weeks depending on the type of fertilizer, frequency of irrigation, and soil characteristics. Uptake is much faster in container nurseries where artificial growing media allow quick penetration and easy availability of mineral nutrients.

Unless specific nutritional problems have been identified, the most attention should be give to the "fertilizer elements"—nitrogen, phosphorus, and potassium. Of these, nitrogen is by far the most important, as it controls so many aspects of seedling growth. The tendency in nurseries is to overfertilize "just to make sure," and because fertilizer is relatively inexpensive. A good example can be seen from phosphorus fertilizer trials (van den Driessche 1984b, 1990) with Douglas-fir and white spruce (*Picea glauca*). Growth curves show that seedling biomass increases rapidly with more phosphorus fertilizer, but quickly peaks at around 0.2% (Figure 2B). This response is further confirmed by a photograph of an experiment testing seedling height versus fertilization level (Figure 2C), demonstrating that only 10 to 15 ppm of available phosphorus are necessary when applied early in the growing season.

Diagnosing Seedling Problems

Many growers test plant tissue in order to diagnose a growth problem. It's important to send paired samples (the more the better for calculation of an accurate mean) of seedling tissue (healthy versus symptomatic) so that comparisons can be made. Some problems, like nitrogen chlorosis, are relatively easy to identify (Figure 3). Unfortunately, by the time the problem is diagnosed, severe growth loss has already occurred.

Most nutritional problems are not that simple, and iron chlorosis is a good example. Because it is immobile in plants, a lack of iron availability induces chlorosis in the younger foliage, which quickly causes severe metabolic problems and subsequent stunting. Once chlorosis and stunting occur, the plants are so "physiologically confused" that they continue to uptake iron, but in a form that is unavailable (Landis 1985). The result is an accumulation of iron in the plants and, typically, concentrations are greater in the chlorotic foliage (Table 4). So, without considerable background knowledge and experience, tissue tests by themselves are of dubious value in diagnosing iron chlorosis and generally just confuse the issue.

Correlating with Outplanting Performance

The final application of plant nutrient testing in forest and conservation nurseries is for the determination of seedling quality and outplanting success. Nitrogen is the only nutrient that has been statistically correlated to outplanting performance and, even at that, there are only a few published research trials that show good correlation (Figure 4). This is one instance in which nutrient content is more useful than concentration.

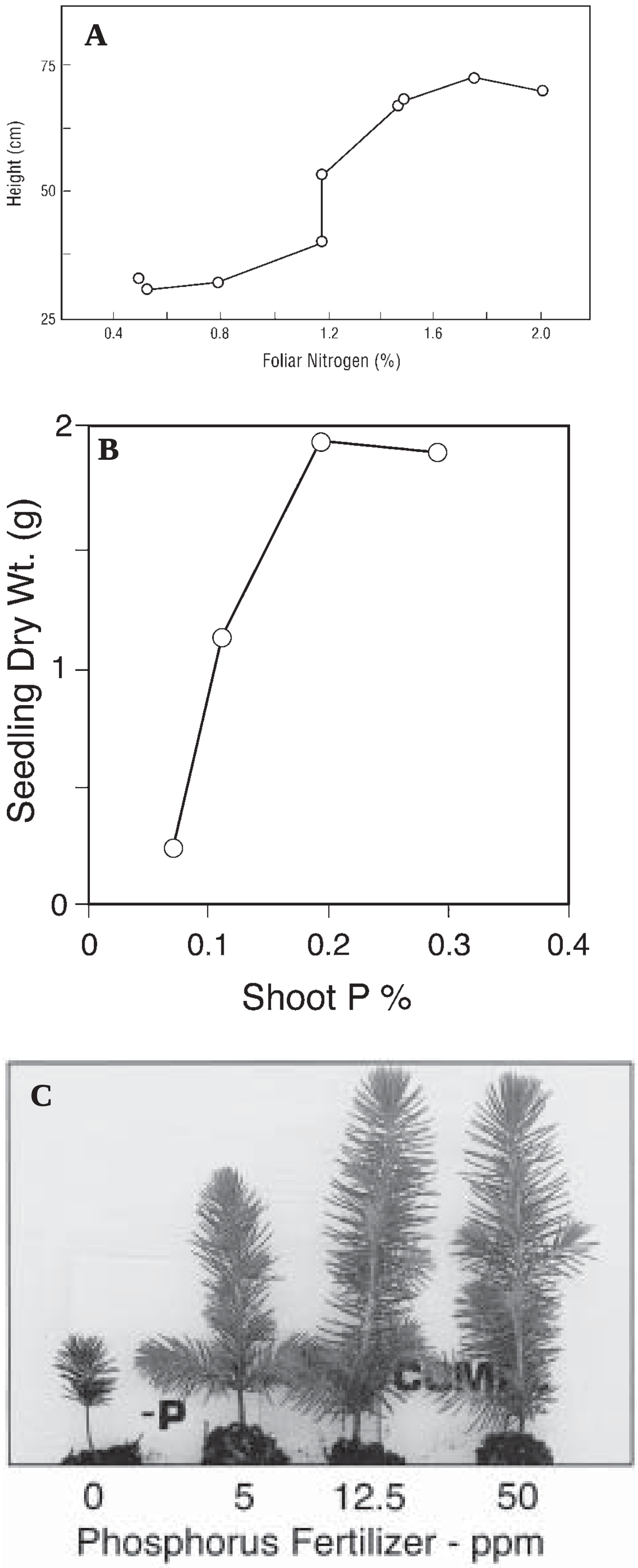

Figure 2—Foliar nutrient levels should be compared against growth curves and fertilizer trials: (A) nitrogen concentration and growth of eastern redcedar (Henry and others 1992); (B) shoot growth versus foliar phosphorus in white spruce (van den Driessche 1984b); (C) phosphorus fertilizer trials with white spruce (van den Driessche 1990).

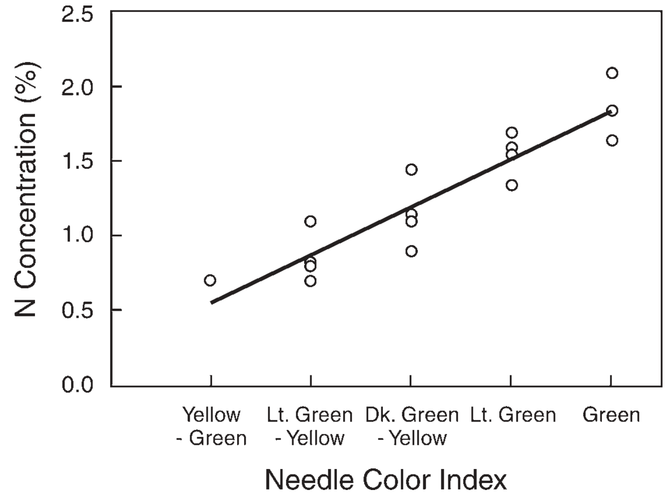

Figure 3—The relationship between nitrogen concentration and green color of Norway spruce needles in Southern Sweden (adapted from Bergquist and Orlander 1988).

The latest research into the relationship between seedling nutrient levels and outplanting performance involves a concept called "nutrient loading" with nitrogen. The idea is that "supercharging" a seedling with nitrogen will help it survive and grow better on the outplanting site where mineral nutrients are usually limiting. Nutrient loading involves fertilizing seedlings during the hardening phase until their nitrogen content is in the luxury consumption area of the growth curves (Figure 5). This process has been successful with black spruce (*Picea mariana*) on sites with heavy plant competition, as chronicled by Timmer and his associates (for example, Timmer 1997).

Nutrient loading is certainly attractive and it is hoped that this technique will be tested with more species and on more outplanting sites. Nutrient loading, however, should not be viewed as a panacea because other factors may be more limiting to survival and growth on specific sites. Water, in particular, is often the most limiting factor after planting regardless of soil nutrient levels. In addition, animal damage may be a problem because nursery seedlings are often preferentially browsed because of their higher nutrient content (Bergquist and Olander 1998).

Table 4—A comparison of foliar iron levels of healthy and chlorotic seedlings at three Intermountain nurseries (modified from Landis 1985).

	Iron concentration in seedling foliage[a]	
Nursery and location	**Healthy seedlings**	**Chlorotic seedlings**
	- - - - - - - ppm - - - - - - - -	
Mt. Sopris Nursery, CO	302	422
Colorado State Nursery, CO	217	346
Albuquerque Nursery, NM	303	624

[a]Recommended range = 50 to 100 ppm.

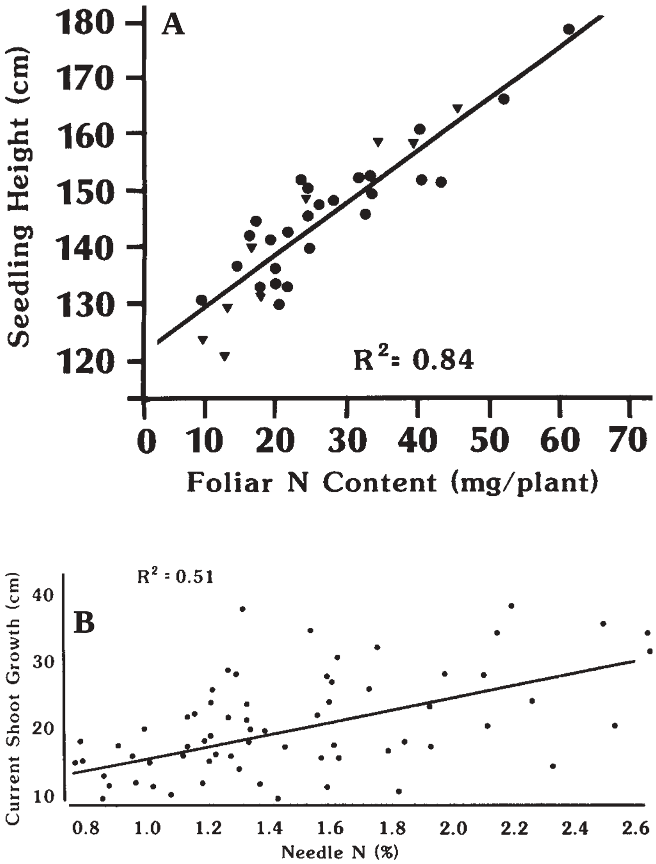

Figure 4— When correlating foliar nitrogen to outplanting performance, nitrogen content (A) has more predictive value than concentration (B) (A—modified from Switzer and Nelson 1963; B—modified from van den Driessche 1984b).

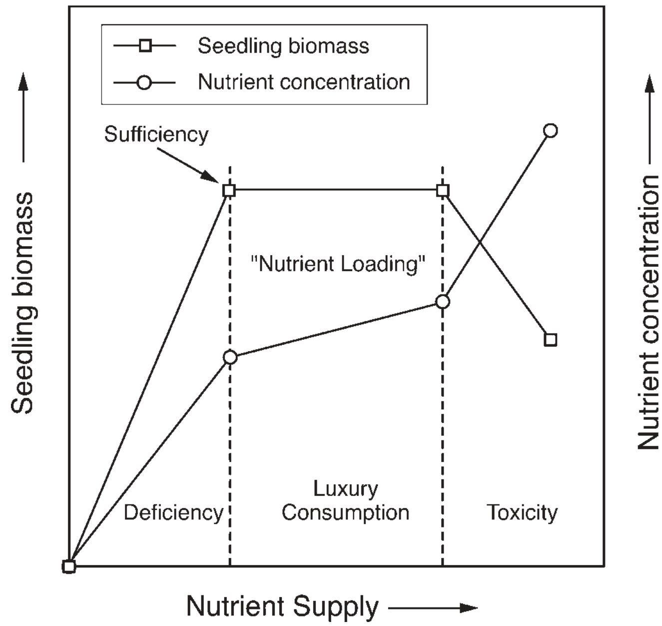

Figure 5—Nutrient loading involves building up nitrogen reserves in the foliage by adding nitrogen fertilizer to induce luxury consumption without changing maximum growth or inducing toxicity (Timmer 1997).

Conclusions and Recommendations

- Plant nutrient analysis during the growing season is an effective and relatively inexpensive way to monitor fertilization effectiveness.
- It's best to develop your own standards using growth response curves or fertilizer trials.
- Plant nutrient analysis can be useful in diagnosing nursery problems, but results are often difficult to interpret.
- By itself, plant nutrition has limited use as a predictor of outplanting performance because water availability is often the most limiting factor on a site.

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Fire Restoration in the Northern Region, USDA Forest Service

Glenda Scott
Steve Shelly
Jim Olivarez

Glenda Scott is the Reforestation/TSI Specialist for USDA Forest Service, Region 1, Federal Building, PO Box 7669, Missoula, MT 59807; telephone: 406.329.3122; e-mail: glscott@fs.fed.us. Steve Shelly is the Regional Botanist for USDA Forest Service, Region 1, Federal Building, PO Box 7669, Missoula, MT 59807; telephone: 406.329.3041; e-mail: sshelly@fs.fed.us. Jim Olivarez is the Regional Program Leader for Invasive Species and Native Plants for USDA Forest Service, Region 1, Federal Building, PO Box 7669, Missoula, MT 59807; telephone: 406.329.3621; e-mail: jolivarez@fs.fed.us

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Abstract: Restoring native plant communities is a key objective in the maintenance of healthy ecosystems. Opportunities have increased following recent wildfires. This paper describes the policy and history behind the reforestation and restoration programs in the Northern Region (Region 1) of the USDA Forest Service, which focused primarily on meeting the objectives in the National Fire Plan, Key Point 2, Rehabilitation and Restoration. The discussion continues with an overview of the rehabilitation efforts in response to nearly 13 million ac (5.3 million ha) of National Forest Lands that have burned in the Northern Region since 2000. Both conifer regeneration and the development and implementation of the native plants program are discussed, and project examples are provided.

Keywords: native plants, reforestation, fire restoration

Background and Policy

The Northern Region (Region 1) of the USDA Forest Service established policy in 1994 to promote the use of native plant materials, but it remained a fledgling program with little program funding and lacking broad-scale emphasis until recently. At the National level, draft policy was recently prepared to promote the use of all types of native plants within the Forest Service. Native plant materials should be the first choice in most situations where timely regeneration of native plant communities is not likely to occur. This policy is one of the components in the implementation of the Forest Service priorities to combat invasive species and facilitate wildland restoration efforts.

The wildfires of 2000 prompted a movement toward managing the impact of wildfires on communities and the environment with the National Fire Plan. Key Point 2 of the plan, Rehabilitation and Restoration, focuses on recovery after disturbance and provides emphasis and funding for a variety of activities including forest reforestation, watershed restoration, road and trail rehabilitation, replanting and seeding. Since implementation, it has provided a major boost to the native plants program.

In Region 1, the impact of the 2000 fires was significant, being the largest fire year on Forest Service lands in recent history. Over 700,000 ac (283,000 ha) of National Forest land in Region 1 burned in 2000, affecting a variety of forest and rangeland ecosystems (Figure 1). It was followed in 2003 by wildfires that burned nearly 400,000 ac (162,000 ha). This has expanded our opportunity to utilize the National Fire Plan and the more recent Healthy Forest Initiative to develop a stronger restoration and rehabilitation program.

Conifer Regeneration

The regeneration of forest cover has historically been a large part of fire restoration. Most burned areas naturally regenerate. In some cases, this is a long regeneration period, passing through successional stages of grass and shrub stages on dry ponderosa pine (*Pinus ponderosa*) forest types. In other cases, natural regeneration is quick to establish, as in lodgepole pine

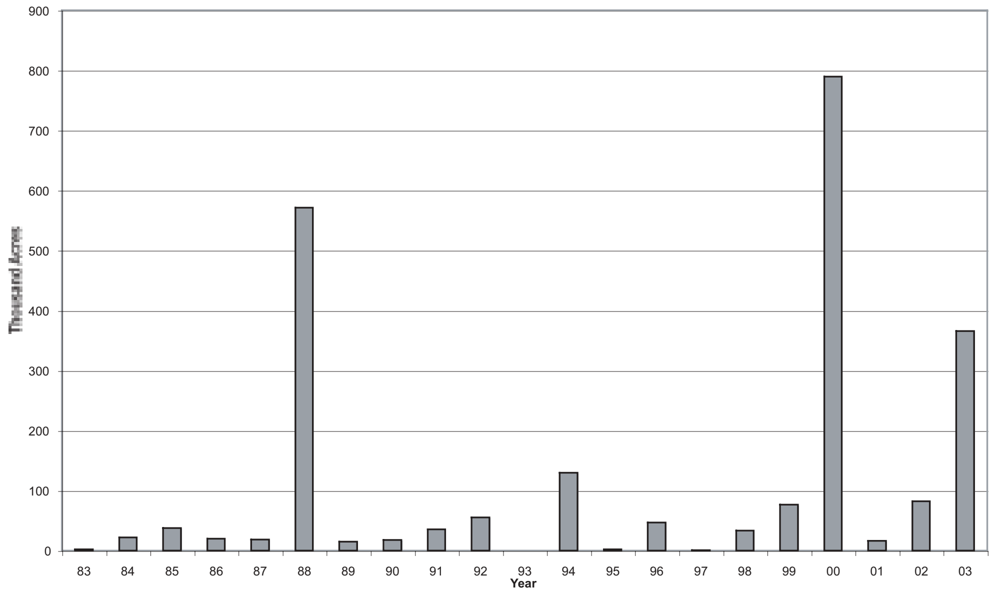

Figure 1—Acres burned by wildfire from 1983 to 2003.

(*P. contorta*) forests. Other portions of the fire areas have high mortality, and forb and shrub reestablishment occurs under the standing dead canopy. A small portion of the fire area is planted to provide rapid tree cover.

Restoring Forest Cover with Planting

Historically, an average of only 10 to 15% of a fire area has been planted. Silviculturists carefully select these areas because they are not predicted to regenerate naturally due to lack of seed source, or will not regenerate to desired seral species. In these cases, it can be said that wildfire has created an opportunity to restore species that, under historic fire regimes, would have dominated the landscape. A good example is in ponderosa pine forests, which have lost dominance to the more shade-tolerant Douglas-fir (*Pseudotsuga menziesii*) in some areas of the Rocky Mountains. The complex of fires in the Bitterroot Valley (Montana) in 2000 created this situation. Planting site-adapted ponderosa pine will restore its dominance on the landscape and can be maintained with management. Another opportunity will be planting rust-resistant western white pine (*Pinus monticola*) following large-scale fires in the moist forests in the western portion of the Region. Recently, large scale fires have not burned in these moist forest types, but fire risk is increasing.

Seed Bank

The ability to respond to restoration opportunities is dependent on having an available seed cache. Prior to the fires of 2000, the Bitterroot National Forest did not anticipate the need for large quantities of ponderosa pine seeds to reforest after a large fire event. Neither the Bitterroot nor adjacent Forests within seed transfer zones had sufficient seeds to produce trees for the acres needing planting. Both 2001 and 2002 proved to be good cone crop years, however, and the needed 1,700 bushels were collected.

This prompted a Regional review of the conifer seed bank to assure adequate seeds were available. The Region has moved from seed zones to genetically based breeding zones for most species. These tend to be larger and cross administrative boundaries. By managing available seeds at the breeding zone level, based on the Forest's projected needs, we feel we are better prepared to respond to large-scale fire planting while not overburdening the bank with excess seeds.

Progress

Overall, about 85,000 ac (34,400 ha) of planting for post-fire reforestation were identified since 2000. Of this, about 35,000 ac (14,200 ha) were older plantations that were destroyed. To date, about 20,000 ac (8,100 ha) have been planted, and additional trees are ordered for outyear planting. Predicted needs for future planting exceed the predicted funding levels; but we are hopeful that we will receive assistance to meet our needs.

Planting after post-fire salvage harvest is the top priority for planting, followed by destroyed plantations, and finally, unmanaged (uncut) lands. The major species being planted include ponderosa pine, Douglas-fir (on some sites), and small levels of lodgepole pine and Engelmann spruce (*Picea engelmanii*). Western white pine and western larch (*Larix occidentalis*) are priority species also, but the moist forests have not experienced large-scale fire in recent years. Silviculturists select the most suitable planting window and stock type. Spring planting of both bareroot and container stock is most prevalent, with lesser amounts of fall and summer planting of container stock. On cool, higher elevation sites, summer planting of actively growing container stock in early July has proved very successful.

Native Plant Restoration

While conifers surely are native plants, they have been addressed separately due to traditional Forest Service program and budget practices. This section deals with forbs, shrubs, grasses, and non-traditional conifers (that is, whitebark pine [*Pinus albicaulis*]). The emphasis on the native plant program has increased dramatically under the National Fire Plan Key Point 2. Region 1 has received nearly U.S. $2 million for assessment work at the Regional level to support the USDA Forest Service Coeur d'Alene Nursery, and for local seed collections, plant propagation, and project implementation on the National Forests.

Most of the wildfire areas heal with natural succession. However, in selected areas, planting and seeding native plant material enhances the natural processes to achieve the desired condition more quickly, and, in some cases, to give native plants competitive advantage over invasive species. The overriding objective of the native plant materials program is to replace the use of non-native plant material with the use of native species. The following sections describe various aspects of the native plant materials program that have been developed with the recent program emphasis.

Identification of Priority Species

Region 1 identified 6 "workhorse" species that have widespread use and function based on candidate species specified by the National Forests in the Region. These species were selected because they are common on the landscape, there was experience in cultivation, and program managers felt there was enough knowledge and experience to succeed with these species. Although there is not exclusive use of these species, identifying priority species has allowed development and genetics work to be more focused and to improve progress.

The workhorse species currently under focused development include: tufted hairgrass (*Deschampsia caespitosa*), blue wildrye (*Elymus glaucus*), Idaho fescue (*Festuca idahoensis*), Sandberg's bluegrass (*Poa secunda*), bluebunch wheatgrass (*Pseudoroegneria spicata*), and yarrow (*Achillea millefolium*).

Plant Development Work

The Region developed an interagency partnership with the Natural Resources Conservation Service (NRCS) Aberdeen Plant Materials Center (PMC) for the development of local seed sources adapted for the Northern Rockies for these workhorse species. Over 50 collections were made from 7 National Forests in Region 1. Field trials at Aberdeen PMC are in progress to evaluate growth characteristics, including performance, seed production, seed yield, germination, and similar qualities. Selected populations will ultimately be used for seed production and made available for district projects.

Regional Grass Seed Cache

The largest use of native plant materials is aerial seeding following wildfires. To encourage the use of native seeds, the Region purchased 14,000 lb (6,350 kg) of native grass seed cultivars from the commercial market. The cache allows the Forests to easily access large quantities of native seeds where previously they would have depended on commercial mixes. These mixes commonly include non-native species seeds. The 4 cultivars currently available in the seed cache are: mountain brome 'Garnet' (*Bromus marginatus*), Idaho fescue 'Winchester' (*Festuca idahoensis*), Idaho fescue 'Nezpurs' (*Festuca idahoensis*), bluebunch wheatgrass 'Goldar' (*Pseudoroegneria spicata*).

This has proved very successful, with most seeds used for emergency rehabilitation after the 2003 wildfires. The Region is making additional purchases to re-supply the cache. The Forest Service is relying on the native seed industry to provide reliable native cultivars to make this program successful. This partnership with the private sector is important because it demonstrates an economic commitment on our part to further the industry through increased demand for products. While seeding with native cultivars in some cases involves using material that is not "local" to the habitats being restored, Region 1 elected to put these cultivars in use as an interim measure while the local sources are being developed, and as a means of promoting a shift from the previous reliance on non-native species.

Forest Service Nursery New Equipment

With National Fire Plan funding, the Forest Service Nursery in Coeur d'Alene purchased equipment particularly necessary for native plant species for seed processing and growing of forbs and shrubs. A new greenhouse was also built. The Nursery can now better process small seeds, conduct more efficient and accurate seed testing, custom mix seeds as per National Forest request, sow, grow, and cut small seed lots of grasses, and grow more greenhouse seedlings.

Whitebark Pine

The National Fire Plan provided a major boost in funding for the initiation of the whitebark pine blister rust resistance program. Whitebark pine typically grows in high-elevation ecosystems where fire exclusion has resulted in advancing succession and a serious decline in whitebark pine. Coupled with the extensive white pine blister rust (*Cronartium ribicola*) infection and mountain pine beetle (*Dendroctonus ponderosae*) mortality, whitebark pine is declining in many areas. This is of particular concern because whitebark pine seeds are a major food source for the endangered grizzly bear, and the species is an important seral component in upper elevation ecosystems.

Current efforts include cone collection from trees expressing rust resistance, and collection of aeciospores to begin the genetic resistance testing. Additional cones have been collected from trees that express resistance, and the seeds grown for restoration outplantings. Although rust resistance is not known, evaluation is an important intermediate step to maintaining this important species in high-elevation forest ecosystems.

Restoration Projects

With the increase in program emphasis, skills, and funding, there is an increasing number of projects to directly restore native plant communities disturbed by recent wildfires. Plant materials used include grass container plugs, container shrub and herbaceous plants from cuttings and seeds, and bareroot plants (Figure 2). Grass seeds from local collections and from commercially available cultivars appropriate to the site are used for seeding projects. Following are examples of projects implemented to restore native plant communities after wildfires in 2000 through 2003.

Aerial Grass Seeding—The largest restoration activity in terms of acres is aerial grass seeding, which has exceeded 22,000 ac (8,900 ha) since 2000. The emphasis is to shift from the use of non-native species to purely native seed mixes. Seeding is typically part of the emergency burn rehabilitation efforts to provide rapid plant cover for soil stabilization and reduce noxious weed invasion (Figure 3).

Jammer Road Obliteration—Jammer roads resulted from the short line, high-lead logging systems of the 1950s through the 1970s. Fire restoration has provided an opportunity to obliterate these old jammer roads to restore hydrologic function and plant cover. One example is the road rehabilitation on the Bitterroot National Forest (Figure 4). Snowberry (*Symphoricarpos albus*) container seedlings were among the species planted on the roads; the seedlings were cultivated from cuttings collected locally (Figure 2). Ponderosa pine is planted in the harvest area. The entire area was aerially seeded with thickspike wheatgrass (*Elymus macrourus*) and slender wheatgrass (*Elymus trachycaulus*), which are both native.

Figure 3—Aerial seeding native grass species on the Black Mountain Fire, Lolo NF (photo by Andy Kulla).

Figure 2—Handcutting snowberry (*Symphoricarpus albus*) to produce rooted cuttings, Bitterroot NF (photo by Linda Pietarinen).

Rehabilitation of Access Roads—Much like jammer roads, access roads and skid trails after fire and salvage harvest are being revegetated. On the Bitterroot National Forest, snowberry, bluebunch wheatgrass, kinnickinnick (*Arctostaphylos uva-ursi*), white spirea (*Spiraea betulifolia*), rose (*Rosa* spp.), and ninebark (*Physocarpus malvaceus*) container plants were outplanted (Figure 5). Erosion matting was laid down to hold the soil and plants in place until establishment.

Seeding Along Wilderness Trails—Selected trails in the Bob Marshall Wilderness, on the Flathead National Forest in northwest Montana, were hand-seeded to reduce

Figure 4—Jammer road rehabilitation, Bitterroot NF (photo by Craig Odegard).

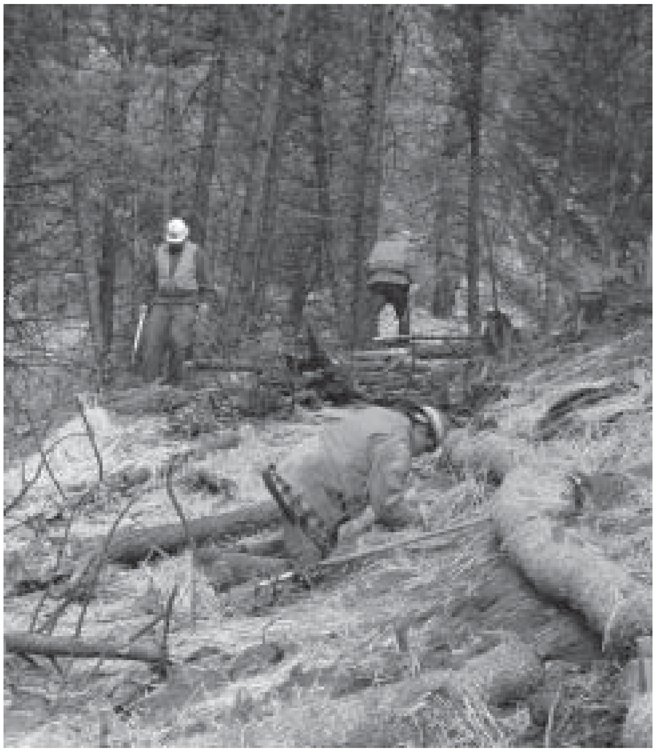

Figure 5—Revegetation of access roads, Bitterroot NF (photo by Craig Odegard).

erosion where trail sloughing was anticipated and to reduce noxious weed invasion after the wildfires in 2000 (Figure 6). On a portion of the trail within the Helen/Lewis II Fire area, blue wildrye (*Elymus glaucus*) was hand-seeded; the seed source was about 20 mi (32 km) from the seeding project. Mountain brome (*Bromus marginatus*) was also used on other trails. Monitoring will continue to determine success of seed germination, native plant recolonization, and effectiveness in reducing erosion and invasion by noxious weeds.

Restoration of Helicopter Landings—Helicopter landings and similar created openings are being planted and seeded as part of the emergency rehabilitation efforts. Rabbitbrush (*Chrysothamnus* spp.) grown in containers was among the desirable species used on the Bitterroot NF due to its suitability on dry harsh sites.

Future Fire Restoration Projects—The work is never done. Six additional projects have been approved for funding for implementation in 2005 and 2006. These include continuation of the whitebark pine blister rust resistance program, restoration of riparian systems, sagebrush communities, grass and forb communities, and additional grass seeding of wilderness trails on Forests throughout Region 1. Depending on the project, the activities may include genetics and development work, seed collection, propagation of small lots, and implementation.

Other Native Plant Restoration Projects—In addition to fire restoration, National Forests have initiated projects for revegetating ski runs, streams impacted by mining, decommissioned roads, steep cut slopes, and many others. As the program develops we expect to see more and larger projects that restore native plant communities. Restoration projects should reach across all resource areas, including road rehabilitation, watershed stabilization, fisheries and wildlife habitat improvement, range restoration, and involvement with the Western Federal Highway Division to establish native plant communities along roadways. The success of the program is dependent on collaboration with government agencies as well as private growers and producers of native plant materials.

Conclusion

The National Forests in Region 1 are responding to the challenge of restoring and reforesting critical plant communities. The increased use of native plant materials, as well as the continued practice of using site-adapted conifers, will enhance the naturally regenerating ecosystems. It is with partners among government agencies and the restoration business that progress is being made toward a more highly developed and proactive native plant materials program. The Forest Service recognizes there must be a long-term commitment to research, development, education, and technology transfer to expand efforts to make native plant materials available. We face challenges, but there is an increased momentum; with the enthusiasm of botanists, ecologists, rangeland management specialists, and foresters, we expect the program to continue and increase.

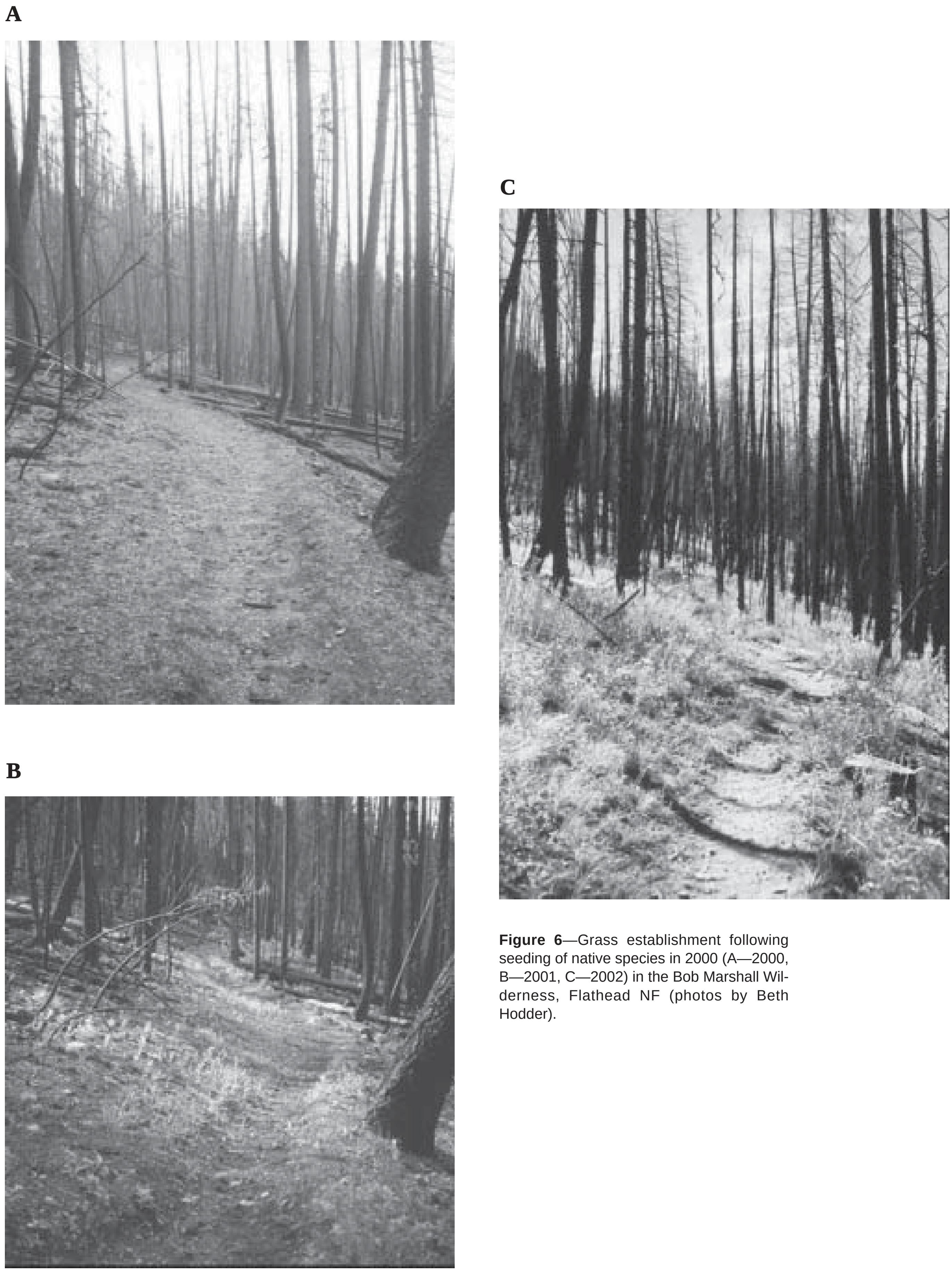

Figure 6—Grass establishment following seeding of native species in 2000 (A—2000, B—2001, C—2002) in the Bob Marshall Wilderness, Flathead NF (photos by Beth Hodder).

Rapid Response Reforestation: Studies in Fire Restoration

Robin Rose
Diane L. Haase

Robin Rose is Director of the Nursery Technology Cooperative, Department of Forest Science, Oregon State University, 321 Richardson Hall, Corvallis, OR 97331; telephone: 541.737.6580; e-mail: robin.rose@orst.edu. Diane L. Haase is Associate Director of the Nursery Technology Cooperative, Department of Forest Science, Oregon State University, 321 Richardson Hall, Corvallis, OR 97331; telephone: 541.737.6576; e-mail: diane.haase@oregonstate.edu

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Abstract: The Nursery Technology Cooperative has been conducting projects to examine forest seedling quality and reforestation success in the Pacific Northwest for more than 20 years. Because of the large wildfires in recent years, there is a growing interest in studying reforestation strategies for optimum restoration following a fire. We have developed 2 "Rapid Response Reforestation" projects to address common reforestation issues in burned areas. Because the number of acres in need of planting cannot be predicted in advance, it is difficult to have adequate seedling stock, especially 2-year-old stocktypes, available. Furthermore, a delay in outplanting may allow competing vegetation to occupy the area, thereby increasing reforestation costs and decreasing early seedling growth and survival. The first project is designed to compare field performance among 1-year-old stocktypes; the second project is designed to investigate the effects of delayed outplanting and vegetation control on subsequent plantation establishment and growth. A review of reforestation issues following wildfire along with details of the study plans are presented.

Keywords: stocktype, vegetation control, seedling, outplanting delay, Q-plug

Introduction

The Nursery Technology Cooperative (NTC) at Oregon State University has conducted nursery and reforestation research since 1982. The goal of the cooperative is to improve forest productivity through the use of advanced seedling technology to achieve optimal regeneration. With members in State, private, and Federal forest sectors, the NTC has been the "CSI" (Conifer Seedling Investigators) of forestry in the Pacific Northwest. Based on cooperators' needs, the NTC has completed applied projects in areas such as root development, nutrition, integrated pest management, and chlorophyll fluorescence. In the past year, there has been growing interest, especially among the NTC's Federal participants, to investigate fire restoration issues.

Wildfires are common in the Pacific Northwest and can result in thousands of acres in need of restoration. In an e-mail survey (June 2004), we asked Federal reforestation personnel what their biggest issues were for reforestation following wildfire. Documentation, funding, salvage, and vegetative competition were the primary issues cited (Table 1). Although it is not our position to solve political and economic issues, we can provide statistical input into the biological challenges associated with fire restoration. The objective of this paper is to outline some of the post-fire biological reforestation issues and to describe new projects designed to address these issues.

Stocktype Issues

Because the number of acres in need of outplanting cannot be predicted in advance, it is difficult to have adequate seedling stock available. When using 2-year-old stock, the forester may have to delay outplanting by 3 or more years. This delay period may allow for competing vegetation to occupy the area, thereby increasing reforestation costs and decreasing early seeding growth and survival. The use of 1-year-old stocktypes can reduce the length of time until outplanting an area devastated by fire. Shaw (1996) discussed growth and survival among seedling stocktypes with 1-year-old container stock having lower initial cost and lead time but uncertain performance compared to larger bareroot stock. In our survey, we asked whether or not a single

Table 1—Survey responses to the question, "What are your biggest issues when it comes to reforestation after wildfire?"

Fremont-Winema NF(4 respondents)	1. Fire salvage and reforestation cost much more than treating green stands—is it worth it? Problems with getting fire salvage done in a timely manner, number and arrangement of snags to be left for wildlife, and snag/hazard trees. 2. Available funds are often inadequate for site prep or damage control. 3. Getting trees in the ground before competition and gopher populations occupy the site. 4. Completing and implementing the NEPA document.
Umpqua NF	Loss of 5,000 plantation acres to fire with inadequate funding for planting.
Okanogan-Wenatchee NF	Obtaining adequate funding. Overstocked stands in dry areas are prone to severe fires, which require large reforestation investments.
Rogue River-Siskiyou NF	Location! Moisture is the most limiting factor. Grass seeding and straw bales to control erosion create competition and potential for introducing noxious weeds.
Deschutes NF	Competing vegetation can be attributed to all their reforestation problems.
Malheur NF	*Ceanothus* spp. competition and gopher damage are big issues with no budget to treat either problem.
Medford BLM	NEPA issues and securing funding are more time consuming and problematic than biological concerns or constraints.

seedling stocktype performed better than others for fire restoration. The relative performance among stocktypes varied considerably depending on site conditions, species, and location (Table 2).

NTC Project to Compare 1-Year-Old Stocktypes

This study is designed to compare performance of conifer seedling stocktypes outplanted following wildfire. To maximize the applicability of these results, the number of outplanting sites is just as important as the stocktypes being compared. The following 3 sites were installed in 2004 (with the possibility of additional sites to be outplanted in 2005):

1. Southern Oregon Cascade site (Medford BLM), 3,000 ft (910 m) elevation, 40 mi (64 km) north of Medford, OR—2002 Timbered Rock Fire, Douglas-fir—(*Pseudotsuga menziesii*) (Q-plug, Styro-15, 2+0, 1+1), outplanted March 23, 2004. Additional 2+0 and 1+1 seedlings will be outplanted in 2005.
2. Southern Oregon Coast site (Medford BLM), 3,800 ft (1,160 m) elevation, 25 mi (40 km) northwest of Merlin, OR—2002 Biscuit Fire, Douglas-fir (Q-plug, Styro-15, 1+1), outplanted March 23, 2004. Additional 1+1 and plug+1 seedlings will also be outplanted in 2005.

Table 2—Survey responses to the question, "Have you found that one seedling stocktype or species works better than another for fire restoration?"

Fremont-Winema NF (3 respondents)	1. Best stocktype is 2+1, with 2+0 being okay. Poor performance with 1-year-old stock (possibly due to harsh seasons when using this stock, later hardening, or gopher damage). 2. Depends on site conditions. Prefers 1+1 because they are "meatier" than 1+0 and not as tall as 2+0. 3. Bareroot 2+0 have performed better than 1+0. Recently planted Q-plug and will evaluate.
Umpqua NF	Using a lot of container and Q-plug this year on the Tiller Complex Fire. These are looking very good (better than 2+0). Have not had success with 1+0 bareroot.
Okanogan-Wenatchee NF (2 respondents)	1. Success with spring-planted container or bareroot. For summer planting (Aug to Sep), bareroot generally fail while container does well. Using copper styroblock for all pine and much of their Douglas-fir. 2. Superior performance with 2-year-old bareroot as compared to container stock.
Rogue River-Siskiyou NF	Need to reforest ASAP. Using plugs because of lead time and funding unknowns. Are moving into Q-plugs this fall/spring.
Deschutes NF	No differences found among stocktypes with the exception of some heldover 2+1 ponderosa pine stock on the Eyerly fire (although this stocktype is not practical to grow for fire).
Malheur NF	Using 1+0 and Styro-5 ponderosa pine in fire areas because they tend to do well in rocky, dry sites. Douglas-fir and western larch containers have lower survival—larger seedlings are better for these species.
Medford BLM	Site dictates the stocktype. Using 1+1 Douglas-fir on good soil with higher precipitation but often use container stock to save growing time. Styro-5 ponderosa pine is a consistent performer and lower cost. Minor species do well as Styro-8 or larger.

3. Northeastern Washington site (Wenatchee NF), 4,800 ft (,1460 m) elevation—2002 Deer Point Fire, ponderosa pine—(*Pinus ponderosa*) (Q-plug and 415B), outplanted May 12, 2004. Note: A survey on July 13, 2004, found 98% survival for both stocktypes.

For each site, the same seedlot was used regardless of stocktype. The Q-plug stocktype is a 1-year-old seedling, sown in a 1-in^3 (16-cc) stabilized media plug (International Horticultural Technologies, LLC, Hollister, CA) in mid-winter and grown under greenhouse conditions for several months, transplanted in bareroot beds in early spring, and lifted the following winter. At each outplanting site, the study was installed in a randomized complete block design. Treatment plots were randomly assigned within blocks. Planting was done at an operational spacing. All seedlings are protected from browse with mesh tubes.

Seasonal height, stem diameter, and survival will be measured. Instances of browsing, chlorosis, frost damage, dead tops, and browning will also be recorded. Growth will be calculated by subtracting initial values. Seedlings will continue to be measured annually to determine long-term differences among stocktypes. Data will be analyzed using analysis of variance (ANOVA). Fisher's Protected Least Significant Difference procedure will be used to determine significant differences in data among stocktypes at the a = 0.05 level. Each site will be analyzed separately.

Outplanting Delay Issues ________

Following a disturbance from wildfire, delay until reforestation can have significant impacts on subsequent survival and growth. There is a declining probability of success over time for seedlings outplanted after a fire without vegetation control (Newton and Lavender, unpublished in Sessions and others 2003). In a study with container-grown white spruce (*Picea glauca*) seedlings outplanted after wildfire and salvage logging, there was 93% survival with scarification site prep and 76% without scarification (Densmore and others 1999). In another study, removal of shrubs resulted in increased survival and growth following fire (De las Heras and others 2002). Additionally, the use of grass seeding to control erosion and increase forage can result in significant seedling mortality (Lehmkuhl 2002).

In our survey, respondents cited various delays to outplanting following fire (Table 3) and most noted vegetative competition as a resulting problem. On the Medford BLM District, 10-year records indicate that delays that allowed 2 or more seasons for vegetation to recover after disturbance negatively affected seedling survival and increased the need to interplant and/or replant from an average of 3% with timely outplanting to an average of 22% when delays occurred (Henneman 2004).

Data from the Vegetation Management Research Cooperative (VMRC) indicate significant gains in conifer seedling stem volume with weed control. After 8 years, trees grown in plots with 3 years control of woody weeds, herbaceous weeds, or total weed control had stem volume increases of 81%, 172%, and 307%, respectively, as compared to seedlings grown in plots without control of competing vegetation. Additionally, increasing the weed-free area around a seedling results in increasing growth responses (Rose and others 1999; Rose and Ketchum 2002).

NTC Project to Investigate the Effects of Outplanting Delay and Vegetation Control

This study will be initiated in 2005. Operational stock will be used for each site. Although stock will be outplanted over a 3-year period, the same seedlot, species, and stocktype must be used at each outplanting for each site. To maximize the applicability of these results, 2 to 4 outplanting sites will be selected for inclusion in the study.

Table 3—Survey responses to the question, "Have you had to delay planting after wildfire? If so, why? Did this result in problems such as erosion or competing vegetation?"

Fremont-Winema NF (3 respondents)	1. Planning process takes 2 years anyway, so there is not a need to use 1-year-old stock. Competition is not a problem since grass seeding was stopped. Funding and removal of hazard trees are also delaying factors. 2. Delay due to NEPA (1 year) and harvest (1 year), ordering seedlings, funding, and available personnel. 3. Delay due to NEPA. Problems with vegetative competition result.
Umpqua NF	Delay is largely due to funding.
Okanogan-Wenatchee NF	Delays due to bareroot seedlings not immediately available, fire area too large to handle in a single season, salvage logging (NEPA timelines and public controversy). Can result in substantial competing vegetation on some sites.
Rogue River-Siskiyou NF	Delay due to site prep and fuels reduction to minimize possibility of reburn.
Deschutes NF	Biggest delay due to not enough seedlings to plant. Delays also due to NEPA and salvage. Competing vegetation is a serious problem.
Malheur NF	Planting must wait for logging and NEPA to be completed. Need to get seedlings planted in time to keep them above the *Ceanothus* spp.
Medford BLM	Have been fortunate to be able to plant 14 to 20 months following fire. Erosion is mitigated with grass/forb mixes put down within the first few months after fire.

A factorial treatment structure will be used (outplanting time x vegetation control). Outplanting treatments will be 1, 2, or 3 seasons after wildfire. Vegetation control levels will be: OO, OT, TO, TT. The Ts (treated) and Os (untreated) represent individual years beginning at the time of outplanting. There are a total of 12 treatments (3 outplanting times x 4 vegetation control levels) that will require 4 years to establish.

Vegetation control treatments were selected based on research conducted by the VMRC, which showed that delaying vegetation control for a year may result in a similar or even larger tree growth response than vegetation control initiated at the time of outplanting. (Note: this may also be a result of good site preparation.) We suspect that effect may diminish when outplanting is delayed for 2 or 3 years and competing vegetation has an opportunity to establish.

At each outplanting site, the study will be installed in a randomized complete block design. Each block will consist of 12 randomly assigned treatment plots (1 for each outplanting/vegetation treatment). Outplanting will be done at an operational spacing, and all seedlings will be protected from browse with mesh tubes.

Initial field height and stem diameter will be measured within one month after outplanting, prior to budbreak. Instances of browsing, chlorosis, frost damage, dead tops, and browning will also be recorded. Height, stem diameter, and survival will be assessed again the following September for first season field performance. In addition, the percentage of cover for grasses, forbs, and woody weeds will be estimated for each plot and the primary species recorded for each weed category.

Plots will continue to be measured annually to determine long-term differences among treatments. Data will be analyzed with ANOVA. Each site will be analyzed separately. Tests for normality, linearity, and constant variance of the residuals will be performed to determine if data transformations are necessary. Fisher's Protected Least Significant Difference procedure will be used to determine significant differences in data among treatments at the $\alpha = 0.05$ level.

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Increasing Native Forb Seed Supplies for the Great Basin

Nancy L. Shaw
Scott M. Lambert
Ann M. DeBolt
Mike Pellant

Nancy L. Shaw is Research Botanist, USDA Forest Service, Rocky Mountain Research Station, Boise, ID 83702; telephone: 208.373.4360; e-mail: nshaw@fs.fed.us. Scott M. Lambert is Regional Seed Coordinator, USDI Bureau of Land Management, Boise, ID 83709; e-mail: Scott_Lambert@blm.gov. Ann M. DeBolt is Botanist, USDA Forest Service, Rocky Mountain Research Station, Boise, ID 83702; e-mail: adebolt@fs.fed.us. Mike Pellant is Great Basin Restoration Initiative Coordinator, USDI Bureau of Land Management, Boise, ID 83709; e-mail: Mike_Pellant@blm.gov

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Abstract: Over the last 150 years, excessive grazing, annual weed invasions, increased wildfire frequency, and other human disturbances have negatively impacted native plant communities of the Great Basin. Native plant materials and appropriate planting strategies are needed to re-create diverse communities in areas requiring active restoration. Although native forbs are critical components of most plant communities, available seed supplies remain low. A cooperative research project being conducted by the USDI Bureau of Land Management Great Basin Restoration Initiative, the USDA Forest Service Rocky Mountain Research Station, and collaborators includes efforts to develop 20 native forbs as revegetation species. Research needs include selection of seed sources and development of seed production and wildland seeding technology for each species. Initial seed increase of new seed sources and maintenance of seed supplies will require production at a range of scales, likely creating new marketing niches for the native seed and nursery industries.

Keywords: native forbs, plant materials, seed production, seeding, rangelands

Introduction

The Great Basin Division of the Intermountain Region as defined by Cronquist and others (1972) (Figure 1) on a floristic basis includes the hydrographic Great Basin with no external drainage, as well as the Owyhee Uplands and Snake River Plain of southern Idaho drained by the Snake River. It encompasses about 200,000 mi^2 (518,000 km^2) with more than two-thirds publicly owned.

Although the population of the Great Basin is low, human impacts have been considerable. Livestock grazing in the late 1800s and early 1900s depleted herbaceous vegetation from great expanses, leaving them vulnerable to invasion by less palatable species. "The Western Range," a report prepared by the Secretary of Agriculture (USDA 1936), stated that during the preceding 30 years, about 95% of the public domain was degraded, and forage was depleted on about 67% of public lands.

The Eurasian annual grasses, cheatgrass (*Bromus tectorum*) and medusahead wildrye (*Taeniatherum caput-medusae*), were introduced in the Western States in the late 1800s and spread rapidly across degraded rangelands (Young and Evans 1970; Mack 1986). A 1994 survey of Great Basin States and Washington (Pellant and Hall 1994) indicated that about 17 million ac (6.9 million ha) of USDI Bureau of Land Management (BLM) lands were dominated or infested with cheatgrass, while an additional 60 million ac (24.3 million ha) were classified as vulnerable. D'Antonio and Vitousek (1992) called the spread of cheatgrass "the most significant plant invasion in the modern history of North America." The invasive annuals senesce early and provide continuous mats of fine fuels. These lengthen fire seasons and increase fire frequencies

Figure 1—The Great Basin (Cronquist and others 1972).

and sizes, deplete native vegetation and seedbanks, and open additional areas for weed invasions. The cheatgrass/ wildfire cycle frequently provides conditions for replacement by noxious perennial weeds that are even more difficult to control. In 1996, the spread of invasive species on BLM and USDA Forest Service lands was estimated at 4,000 ac (1,600 ha) per day (USDI BLM 1996).

Pinyon-juniper communities of the Great Basin generally occupy areas at higher elevations that receive somewhat greater precipitation, ranging from 10 to 20 in (25 to 50 cm) per year. Expansion of these communities over the last 150 years has resulted from increasing temperatures, nitrogen, and atmospheric CO_2, heavy post-European settlement livestock grazing, and fire suppression and consequent decreases in fire frequency (Tausch 1999). As a result, these woodlands have expanded into sagebrush and other communities. The conifers provide shade and litter that permit them to out-compete other natives, leaving the soil vulnerable to erosion and colonization by invasive exotics (West and Young 2000).

The above impacts, as well as agricultural development and urbanization, have led to degradation, loss, and fragmentation of plant communities throughout the Great Basin. Protecting the remaining sagebrush and salt desert shrublands, as well as less widespread communities, has become a major challenge within the Great Basin and throughout the Intermountain West. Loss of species diversity in sagebrush communities alone has resulted in at least 338 plant and animal species being considered at risk (Wisdom and others 2003). The decline of sage-grouse, a sagebrush obligate, has led to petitions for population and species listing (Kritz 2004). Restoring their habitat is becoming a major focus of management and restoration efforts.

Great Basin Restoration Initiative

In response to these problems, and in particular to the wildfires of 1999 that burned 1.7 million ac (700,000 ha) of Western rangelands, the Great Basin Restoration Initiative was launched to provide an approach for protecting and restoring native plant communities. The aim of this Initiative is to proactively plan for restoration at the landscape level (USDI BLM 1999, 2000, 2004b). Its 3 major goals are to:

1. Maintain native plant communities where healthy land exists now or can be restored by modifying standard management practices.
2. Restore degraded landscapes to improve land health and reduce invasive species, especially those responsible for altered fire regimes.
3. Sustain long-term multiple use and enjoyment of public land in the Great Basin and provide potential economic opportunities to local communities in the restoration process.

A Coordinator and team are in place and work has been conducted through a number of cooperative research, management, and public sector efforts including:

1. Eastern Nevada Landscape Coalition.
2. Integrating Weed Control for the Great Basin.
3. Coordinated Intermountain Restoration Project.
4. Cheatgrass Risk Assessment Mapping.
5. Southern Idaho Sagebrush/Sage-Grouse Habitat Project.
6. Great Basin Native Plant Selection and Increase Project.

Increasing the Availability and Use of Native Seed Supplies

A major focus of the Great Basin Restoration Initiative has been to accelerate the transition to greater use of native species in restoration seedings on rangelands. Introduced grasses and forbs have long been used to improve forage availability on disturbed rangelands, while native shrubs have been seeded or transplanted to improve disturbed wildlife habitat. Public interest in restoring and protecting biodiversity, repairing degraded ecosystems, and slowing the spread of exotic vegetation has contributed to greater emphasis on the use of native plant materials. This has been formalized in documents recommending use of native species when feasible (USDI and USDA 2002), including Executive Memoranda and Orders (Clinton 1994, 1999), agency regulations, and the FY02 Interior Appropriations Bill.

Recent decades have seen increases in BLM use of regional and local native seed sources. Although some native grasses are collected from wildlands, most available native species are grown as released cultivars and germplasms produced in seed fields. Shrub seeds are generally collected from native wildland stands, while native forb seeds may be wildland collected or produced in seed fields. Figure 2 compares average annual native and introduced seed purchases for the 1985 to 1991 and 1998 to 2002 periods as percentages of the total annual seeds purchased by weight. For the 1998 to 2002 period, nearly 2.9 million lb (1.3 million kg) of seeds were purchased annually. Native seed purchases had increased to 47% of the total compared to 15% for the 1985 to 1991 period. Greatest increases were for native shrub and grass seeds, while native forb purchases continued to represent less than 1% of the total. From 1998 to 2002, an average of 8 of the 69 species purchased were native forbs (Figure 3).

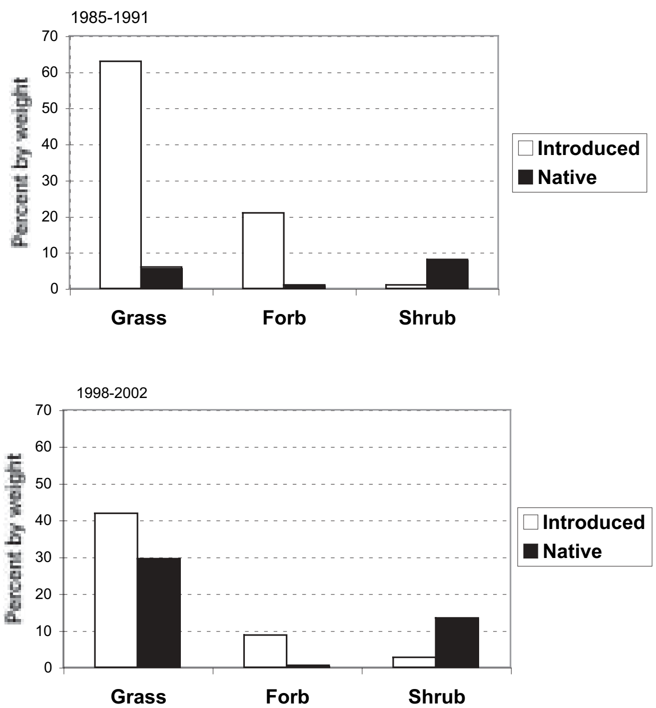

Figure 2—Native and introduced species of grass, forb, and shrub seeds purchased by the USDI Bureau of Land Management from 1985 to 1991 and 1998 to 2002 on a percent by weight basis (USDI BLM 2004a).

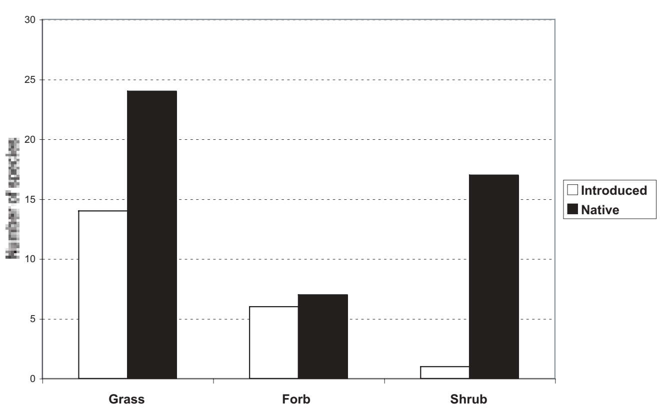

Figure 3—Average number of introduced and native grass, forb, and shrub species purchased annually by the USDI Bureau of Land Management from 1998 to 2002 (USDI BLM 2004a).

Development of a BLM regional seed storage facility in Boise, Idaho, has facilitated revegetation planning and seed purchasing, storage, and distribution. A Regional Seed Coordinator compiles BLM District seed purchase requests. These are advertised for consolidated seed buys, with seeds stored at the Boise location or at warehouses rented or owned by the Districts until needed. Requests for field-grown cultivars or germplasms as well as Source Identified wildland collected seeds (Young and others 2003) are becoming more common. In addition, where use of locally adapted germplasm is a high priority, some Districts may collect or contract seed collection from specific areas. Collected seeds may be used immediately or increased by private growers if larger quantities of seeds are required or if the need for a particular source is expected to extend over a period of years.

The "Guidebook to the Seeds of Native and Non-native Grasses, Forbs, and Shrubs of the Great Basin" (Lambert, forthcoming) provides lists of species suitable for revegetation uses in major plant communities of each Level III Ecoregion (Omernik 1987) within the Great Basin, along with ecological information and characteristics of each species, seed costs, and recommended seeding rates. In addition, some Districts are creating lists of priority revegetation species suitable for widespread plant communities.

Great Basin Native Plant Selection and Increase Project

To increase the availability of native seed supplies, particularly native forbs, for rehabilitation of burned areas and restoration of degraded rangelands in the Great Basin and the technology for their use, a collaborative research project was developed between the USDI BLM and the USDA Forest Service, Rocky Mountain Research Station Shrub Sciences Laboratory and their cooperators (Table 1). Objectives of this group, The Great Basin Native Plant Selection and Increase Project, are to (1) increase the supply of native plant materials available for restoration, (2) manage or restore seed sources on wildlands and develop technology to improve the diversity of introduced grass seedings, and (3) provide technology transfer. Support for this work has been provided through a 5-year agreement with the USDI BLM Great Basin Restoration Initiative and funding from the Native Plant Initiative.

Why Forbs?

Although forbs are components of most native communities, the use of native forbs in revegetation has been limited (McArthur and Young 1999) (Table 2). Forbs are needed to increase biodiversity, resist the spread of weeds, and improve habitat diversity (Shaw and Monsen 1983; Stevens and others 1985; Walker and Shaw, forthcoming). They increase forage quality and season of availability. Forbs provide soil stabilization and cover, and they improve aesthetics of wildlands, recreational sites, and domestic landscapes (Parkinson 2003). Forb fruits, seeds, and leaves are important foods for upland game birds and other organisms. Their importance to sage-grouse (Connelly and others 2000) plays a critical role in considerations for revegetation within the range of this species.

Table 1—Great Basin Native Plant Selection and Increase Project cooperators.

Primary cooperators
USDI Bureau of Land Management, Great Basin Restoration Initiative, and UT, NV, ID, and OR State Offices
USDA Forest Service, Rocky Mountain Research Station, Shrub Sciences Laboratory, Provo, UT, and Boise, ID
Utah Division of Wildlife Resources, Great Basin Research Center, Ephraim, UT
USDA Agricultural Research Service, Forage and Range Research Laboratory, Logan, UT
USDA Natural Resources Conservation Service, Aberdeen Plant Materials Center, Aberdeen, ID
USDA Agricultural Research Service, Bee Biology and Systematics Laboratory, Logan, UT
USDA Agricultural Research Service, Western Regional Plant Introduction Station, Pullman, WA
USDA Forest Service, National Tree Seed Laboratory, Dry Branch, GA
Association of Official Seed Certifying Agencies and State Foundation Seed Programs of ID, NV, OR, UT, and WA
Brigham Young University, Departments of Integrative Biology and Plant and Animal Science, Provo, UT
Colorado State University, Cooperative Extension Service, Tri-River Area, Grand Junction, CO
Oregon State University, Malheur Experiment Station, Ontario, OR
Utah Crop Improvement Association, Logan, UT
Private seed industry
Additional cooperators
Boise State University, Larry Selland College of Applied Technology—Horticulture Program, Boise, ID
Idaho State Department of Agriculture, Seed Laboratory, Boise, ID
Idaho State Department of Fish and Game, Jerome, ID
Nitragin Company, Milwaukee, WI
Oregon State University, Seed Laboratory, Corvallis, OR
Nevada State Seed Laboratory, Carson City, NV
USDA Forest Service, National Forest Genetic Electrophoresis Laboratory, Placerville, CA
USDA Forest Service, Boise National Forest, Lucky Peak Nursery, Boise, ID
USDA Forest Service, Pacific Northwest Research Station, Forestry Sciences Laboratory, Corvallis, OR
USDA Agricultural Research Service, Poisonous Plant Research Laboratory, Logan, UT
Harold Wiedemann (retired), Texas A & M University, College Station, TX

A large number of forb species are present in the Great Basin. They represent a variety of plant families and exhibit differing reproductive strategies, fruit and seed types, sizes, and shapes, and requirements for germination and seedling establishment. Some species are abundant, widely distributed, and occur across a wide variety of environments, while others are narrowly restricted endemics. Literature on the biology of native forbs is generally limited. Thus, considerable effort and resources are required to develop seed production and wildland seeding technology for each candidate revegetation species. This makes difficult the challenge of providing adapted native forb seed supplies for the Great Basin.

Native forbs offer unique problems in seed collecting, handling, and seeding. Seeds of many species are generally hand collected from wildland stands (Davison 2004). Seed production is highly erratic; thus cost and seed availability are unpredictable. Collections are often contaminated with weed seeds. Seed handling guidelines, cleaning methodologies, and storage requirements are generally not known. Standardized seed quality testing procedures have not been developed. Few seed and vegetative propagation protocols for use in seed fields or establishment on wildland sites are available, and guidelines are often fragmentary. Jensen and others (2001), Lambert (1999, forthcoming), Native Plant Network (nd), Shaw and Monsen (1983), Stevens and Monsen (2004), Stevens and others (1985, 1996), Walker and Shaw (forthcoming), and Wasser (1982) provide summaries for some Great Basin species.

To date, few seed sources of native forbs have been developed for the Great Basin. This is illustrated by Table 3, which provides a list of native forbs released by the USDA Natural Resources Conservation Service and their cooperators for the Intermountain area. In addition to released materials, contract growing for agencies and speculation growing of wildland collections made by seed producers or their collectors are now becoming more common.

Forb Research

Selection of species on which to focus research efforts was accomplished through examination of floras, field survey lists, and herbaria. It also included consultations with taxonomists, wildlife biologists, botanists, and revegetation specialists. Consideration was given to species that are fairly widespread in arid and semiarid areas of the Great Basin and are of greatest concern to the BLM, including degraded big sagebrush, salt desert shrub, and pinyon-juniper communities. Seed production characteristics and potential were also evaluated, as markets for individual species are not likely to develop if seed costs are unreasonably high. Likewise, growers are reluctant to begin growing new species if seed production, harvesting, or processing problems appear insurmountable. Forb species initially selected for research plus those added in subsequent years are listed in Table 4. This table also lists grasses and shrubs being studied by cooperators in the Great Basin Native Plant Selection and Increase Project.

Initial research has involved germplasm collection from throughout the Great Basin and surrounding areas for establishment of common gardens and studies of physiological, morphological, and molecular traits. These will aid in evaluating the nature and extent of variability occurring within species and their subspecific taxa, and in determining the ecological and geographic distances that plant materials may be transferred from their site of origin. As yet, seed transfer zones, expected to differ among species, are not available for native forbs. Although a number of classification systems are available (for example, Bailey and others 1994), use of Level III Ecoregions (Omernik 1987) as an interim surrogate for seed transfer zones has been suggested (Withrow-Robinson and Johnson 2004), but with the caution that finer divisions have been necessary for many forest tree species.

Table 2—USDI Bureau of Land Management forb seed purchases in 2000.

Scientific name	Common name	Origin[a]	lb	kg
Medicago spp.	Alfalfa (Ladak and others)	I	99,490	45,130
Sanguisorba minor	Small burnet	I	53,930	24,460
Linum perenne	Blue flax (Appar)	I	51,020	23,140
Onobrychis viciaefolia	Sainfoin	I	40,100	18,190
Achillea millefolium	Western yarrow	N	12,290	5,570
Melilotus officinalis	Yellow sweet clover	I	12,050	5,470
Astragulus cicer	Cicer milkvetch	I	6,250	2,830
Penstemon palmeri	Palmer penstemon	N	810	370
Sphaeralcea grossulariifolia	Gooseberryleaf globemallow	N	390	180
Helianthus spp.	Sunflower	N	230	105
Cleome serrulata	Rocky Mountain beeplant	N	100	45
Helianthus annuus	Annual sunflowers	N	90	40
Sphaeralcea munroana	Munro globemallow	N	50	20
Penstemon strictus	Rocky Mountain penstemon	N	30	15

[a] I = introduced, N = native.

Table 3—Native forbs released by the USDA Natural Resources Conservation Service and their cooperators for the Intermountain area[a].

Scientific name	Common name	Origin	Release	Class
Artemisia ludoviciana	Louisiana sage	ID	Summit	Cultivar
Eriogonum niveum	Snow buckwheat	OR	Umatilla	Cultivar
Eriogonum umbellatum	Sulfur buckwheat	CA	Sierra	Cultivar
Hedysarum boreale	Utah sweetvetch	UT	Timp	Cultivar
Linum lewisii	Lewis flax	UT	Maple Grove	Selected
Penstemon angustifolius	Narrow leaf penstemon	NM	San Juan	Selected
Penstemon eatonii	Eaton penstemon	UT	Richfield	Selected
Penstemon palmeri	Palmer penstemon	UT	Cedar	Cultivar
Penstemon strictus	Rocky Mountain penstemon	NM	Bandera	Cultivar
Penstemon venustus	Venus penstemon	ID	Clearwater	Selected
Sphaeralcea coccinea	Scarlet globemallow	ID	ARS-2936	Selected
Sphaeralcea munroana	Munro globemallow	UT	ARS-2892	Selected

[a] Englert and others (2002).

Basic studies of plant life histories, particularly phenological development, breeding systems, and seed biology and ecology, provide data required for developing agricultural seed production systems for individual species. In some cases, species identified here or related species have been used in revegetation efforts. Knowledge gaps are identified and research is being conducted to develop technology needed for all phases of seeding, harvesting, handling, testing, and storage. Seed dormancy is particularly problematic for field or nursery establishment of most Great Basin forbs due to long prechill requirements.

Species-specific cultural practices are required to produce reliable seed crops at reasonable prices. Ongoing research on herbicide tolerances and appropriate application rates will permit control of common weeds with minimal impact to the forb species being propagated. Irrigation studies are being conducted to determine water requirements and evaluate the feasibility of using drip irrigation to conserve water and discourage weed growth. Determination of specific soil conditions, seedbed microsite requirements, and inoculum specificity for legumes are providing growers with guidelines for seeding to improve the return from limited quantities of seeds during initial increases. This data will also aid in developing strategies for establishing the species in wildland seedings.

Insects are important as pollinators of many forb species and as predators of seeds and vegetative plant parts. Studies of breeding systems and native populations are aiding in determining whether reproduction is pollinator-limited. Identified pollinators of wild populations and currently managed bee species are being tested as pollinators for seed production fields. This research will contribute to knowledge of pollination requirements and use and management of captive pollinator populations where appropriate to improve seed production. Seed and plant predatory insects become problematic where host species are seeded as monocultures. Determination of areas of occurrence, host species, and life histories are contributing to development of management strategies.

Products of forb research will include native forb plant materials adapted to defined areas of the Great Basin and the technology required to produce and maintain seed supplies of each. This technology will provide a basis for developing appropriate seeding technology for establishing these species on wildland sites.

Table 4—Grass, forb, and shrub species included in the Great Basin Native Plant Selection and Increase Project.

Family species	Common name	Growth form
Apiaceae		
Lomatium dissectum	Fern-leaf biscuitroot	Forb
Lomatium grayi	Gray's biscuitroot	Forb
Lomatium nuttallii	Nuttall desert parsley	Forb
Lomatium triternatum	Nineleaf biscuitroot	Forb
Asteraceae		
Achillea millefolium	Western yarrow	Forb
Agoseris glauca	Pale agoseris	Forb
Artemisia tridentata	Big sagebrush	Shrub
Balsamorhiza hookeri	Hooker balsamroot	Forb
Balsamorhiza sagittata	Arrowleaf balsamroot	Forb
Chrysothamnus nauseosus	Rubber rabbitbrush	Shrub
Crepis acuminata	Tapertip hawksbeard	Forb
Erigeron pumilus	Shaggy fleabane	Forb
Capparidaceae		
Cleome lutea	Yellow beeplant	Forb
Chenopodiaceae		
Atriplex canescens	Fourwing saltbush	Shrub
Ceratoides lanata	Winterfat	Shrub
Fabaceae		
Astragalus eremiticus	Hermit milkvetch	Forb
Astragalus filipes	Threadstalk milkvetch	Forb
Astragalus utahensis	Utah milkvetch	Forb
Hedysarum boreale	Utah sweetvetch	Forb
Lupinus argenteus	Silvery lupine	Forb
Lupinus sericeus	Silky lupine	Forb
Vicia americana	American vetch	Forb
Viguiera multiflora	Showy goldeneye	Forb
Liliaceae		
Allium acuminatum	Tapertip onion	Forb
Linaceae		
Linum lewisii	Lewis flax	Forb
Malvaceae		
Sphaeralcea coccinea	Scarlet globemallow	Forb
Sphaeralcea grossulariifolia	Gooseberryleaf globemallow	Forb
Sphaeralcea munroana	Munro globemallow	Forb
Poaceae		
Achnatherum hymenoides	Indian ricegrass	Grass
Achnatherum thurberianum	Thurber needlegrass	Grass
Hesperostipa comata	Needle and thread	Grass
Elymus elymoides	Squirreltail	Grass
Elymus multisetus	Big squirreltail	Grass
Leymus cinereus	Basin wildrye	Grass
Pascopyrum smithii	Western wheatgrass	Grass
Poa secunda	Sandberg bluegrass	Grass
Pseudoroegneria spicata	Bluebunch wheatgrass	Grass
Polemoniaceae		
Phlox longifolia	Longleaf phlox	Forb
Polygonaceae		
Eriogonum heracleoides	Wyeth buckwheat	Forb
Eriogonum ovalifolium	Cushion buckwheat	Forb
Eriogonum umbellatum	Sulfur buckwheat	Forb
Rosaceae		
Purshia tridentata	Bitterbrush	Shrub
Scrophulariaceae		
Penstemon acuminatus	Sharpleaf penstemon	Forb
Penstemon cyaneus	Blue penstemon	Forb
Penstemon deustus	Scabland penstemon	Forb
Penstemon pachyphyllus	Thick-leaf penstemon	Forb
Penstemon palmeri	Palmer penstemon	Forb
Penstemon speciosus	Sagebrush penstemon	Forb

Seed Increase: The Native Seed and Nursery Industry Connection

The private sector native seed and nursery industries are extremely important components of the native forb development project. The selection and increase of native forb materials has been handled through the conventional variety release program administered by Foundation Seed programs in each State for crop species. An alternative, the Pre-Variety Germplasm (PVG) system, was developed to provide native plant materials when supplies of seeds or vegetative materials are needed quickly in somewhat limited quantities, generally for specific geographic areas (Young and others 2003). Materials are released through this system as Source Identified, Selected, Tested, or Cultivar/Variety. Pre-variety germplasm releases can be tracked by State seed certification systems.

Two programs are available for seed growers or nurseries willing to grow small lots of native forbs, Utah's Foundation Seed Program and the Cooperative Native Seed Increase Program. A buy-back program, operated by Utah's Foundation Seed Program and supported in part by the Native Plant Selection and Increase Project, provides early generation seeds of new releases to growers and includes a buy-back option in the contract to purchase seeds from the first crop for distribution to secondary growers. Information on this program may be obtained from Stanford Young, Seed Certification Specialist, Utah State University, Logan, UT (e-mail: sayoung@mendel.usu.edu).

The Association of Official Seed Certifying Agencies (AOSCA) and Foundation Seed Agencies in Idaho, Nevada, Oregon, Utah, eastern Washington, and other areas surrounding the Great Basin administer the second program known as the Cooperative Native Seed Increase Program (USDA FS nd). Small quantities of Source-Identified seeds collected from areas of revegetation concern to the BLM are provided to seed growers along with available knowledge and literature on seed production of the species or of related species. Foundation Seed Agencies will purchase seeds during the first 2 crop years up to an agreed upon minimum. Additional seeds not purchased by State agencies can be sold on the open market as G2 seeds. Growers also agree to provide records of their cultural practices applied to production of these seeds. When initial wildland collections of desired populations are extremely small, initial increase may be grown at a State or Federal nursery, a NRCS Plant Material Center, or university field site. Details of this program may be obtained by contacting Ann DeBolt, USDA Forest Service, Rocky Mountain Research Station, Boise, ID (e-mail: adebolt@fs.fed.us). Table 5 lists the species currently being increased through these 2 programs.

Summary

Although forbs are components of most native plant communities, the incorporation of native forb species in revegetation projects in the Great Basin has been limited, largely due to inadequate seed supplies. Recognition of forb values for increased biodiversity, soil stabilization, improved aesthetics and wildlife, and the critical shortages realized after the 1999 and 2000 fire seasons has boosted efforts to increase their supplies. Through the Great Basin Restoration Initiative and subsequent development of the Great Basin Native Plant Selection and Increase Project, collaborative on-going research and partnerships focused on increasing the supply of native plant materials, managing and restoring seed sources on wildlands, developing technology to improve the diversity of introduced grass seedings, and technology transfer products will create and

Table 5—Native species being increased through the AOSCA Cooperative Native Seed Increase and Buy-back Programs.

Species	Common name	Seed origin	Production State	AOSCA	Buy-back
Achillea millefolium	Western yarrow (Eagle)	ID	WA		X
Achnatherum thurberianum	Thurber needlegrass	ID, NV	ID	X	X
Balsamorhiza hookeri	Hooker balsamroot	ID	CO, ID		X
Balsamorhiza sagittata	Arrowleaf balsamroot	NV, OR	ID, UT	X	
Crepis acuminata	Tapertip hawksbeard	NV	NV, UT	X	X
Cleome lutea	Yellow beeplant	NV	NV	X	
Eriogonum heracleoides	Wyeth buckwheat	ID	UT	X	
Eriogonum ovalifolium	Cushion buckwheat	NV	NV	X	
Eriogonum umbellatum	Sulfur buckwheat	NV	ID	X	
Lomatium dissectum	Fern-leaf biscuitroot	ID, OR	NV, UT	X	X
Lomatium triternatum	Nineleaf biscuitroot	ID	ID, OR		X
Penstemon acuminatus	Sharpleaf penstemon	ID	OR		X
Penstemon cyaneus	Blue penstemon	ID	CO, ID, WA	X	X
Penstemon deustus	Scabland penstemon	ID	ID		X
Penstemon pachyphyllus	Thickleaf penstemon	UT	OR		X
Penstemon speciosus	Sagebrush penstemon	ID, OR	ID, UT	X	
Poa secunda	Sandberg bluegrass (Mtn. Home)	ID	WA		X
Pseudoroegneria spicata	Anatone bluebunch wheatgrass	WA	ID, OR, WA		X
Sphaeralcea grossulariifolia	Gooseberryleaf globemallow	NV	OR		X
Sphaeralcea munroana	Munro globemallow	OR	OR	X	
Sphaeralcea parvifolia	Smallflower globemallow	UT	CO		X

stabilize markets for the native seed and nursery industries while restoring important native plant communities.

Acknowledgment

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Arbuscular Mycorrhizal Inoculation Following Biocide Treatment Improves *Calocedrus decurrens* Survival and Growth in Nursery and Outplanting Sites

Michael Amaranthus
David Steinfeld

Michael Amaranthus is Adjunct Associate Professor, Forest Science Department, Oregon State University, and President, Mycorrhizal Applications, Inc., PO Box 1181, Grants Pass, OR 97528; telephone: 541.476.3985; e-mail: drmike@mycorrhizae.com. David Steinfeld is Soil Scientist, Rogue River National Forest, 2606 Old Stage Road, Central Point, OR 97502; telephone: 541.858.6105; e-mail: dsteinfeld@fs.fed.us

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Abstract: Commercial production of tree seedlings often includes various biocidal soil treatments for disease control. Such treatments can be effective in eliminating or reducing disease organisms in the soil, but may also eliminate non-targeted beneficial soil organisms, such as mycorrhizal fungi, that improve seedling performance, both in the nursery as well as the outplanted environment. The arbuscular mycorrhizal fungal (AMF) relationship has been verified for some important western coniferous species such as incense cedar (*Calocedrus decurrens* [Torr.] Florin), coastal redwood (*Sequoia sempervirens* [D. Don] Endl), and western redcedar (*Thuja plicata* J. Donne ex D. Don).

This study was designed to determine the response of incense cedar after soil fumigation with and without the addition of phosphorous fertilizer and a commercial mycorrhizal inoculant containing *Glomus intraradices*. Incense cedar seedling performance was monitored in both the nursery and outplanting environments.

At the nursery, non-mycorrhizal seedlings had significantly less foliar phosphorous levels even when phosphorous fertilizers were applied. Mycorrhizal inoculation at the nursery significantly improved height and seedling survival on treated plots. Seedlings from the nursery beds were then outplanted on 2 reforestation sites. Mycorrhizal inoculation at the nursery improved survival and growth of seedlings at the outplanted site.

Keywords: bareroot seedlings, nursery culture, outplanting performance

Introduction

Under natural conditions, most plants live in close beneficial association with soil microorganisms called mycorrhizal fungi. These fungi colonize plant roots and extend the root system into the surrounding soil to form an essential link between plant and soil environment. Mycorrhizal mycelia are extensions of the plant root system and are more effective in nutrient and water absorption than plant roots by themselves. The relationship is mutually beneficial because the fungus receives essential sugars and other compounds from the plant to fuel its activities and, in return, it increases plant nutrient and water uptake, increases plant resistance to disease, and extends protection against a wide variety of environmental extremes (Harley and Smith 1983; Allen 1991). All conifer species are known to form and be dependent upon the mycorrhizal relationship in their native habitats.

Commercial production of tree seedlings often includes various biocidal soil treatments for disease control. Such treatments can be effective in eliminating or reducing disease organisms, but may also eliminate non-target beneficial soil organisms, such as mycorrhizal fungi (Menge 1982; Trappe and others 1984; Kough and others 1985). Research has shown mycorrhizal fungi are critical to the uptake of water and nutrients and seedling survival across a wide range of host and field conditions (Jackson and others 1998; Miller and others 1998; Amaranthus and Steinfeld 2003; Steinfeld and others 2003). However, nursery conditions in which water and nutrients are amply provided can decrease the need and observed benefits of the mycorrhizal relationship. This is especially true when phosphorous is readily available (Harley 1978; Browning and Whitney 1992). Numerous practitioners, however, have observed stunting and uneven growth of conifers following biocidal treatments even after soil analysis reveals adequate levels of soil fertility. Many of these cases of uneven growth and nutrient deficiencies following biocidal treatment have documented improved growth and nutrition when inoculated with the appropriate mycorrhizal fungus (Bartschi and others 1981; Parke 1982; Parke and others 1983). In these cases, poor growth of many conifer species, despite adequate soil fertilization, may be due to the coarse root systems lacking root hairs. Mycorrhizal fungi augment the root hairs by providing increased surface area and enzyme activity to release immobile soil nutrients, such as phosphorous, zinc, copper, and others (St John 1979).

Mycorrhizal fungi can profoundly affect seedling performance in the field by mediating nutrient and water uptake and protecting against environmental extremes in the narrow window for seedling establishment (Harley and Smith 1983; Steinfeld and others 2003; Amaranthus and others 2004b). A typical forest site generally contains many mycorrhiza-forming fungal species (Amaranthus and others 1996), but populations can be dramatically reduced or eliminated following site disturbance (Perry and others 1987; Amaranthus and Trappe 1993; Page-Dumroese and others 1998). Seedlings inoculated at the nursery with the appropriate mycorrhizal fungi *before* outplanting have the ability to more quickly assimilate site resources during the critical period of seedling establishment.

The arbuscular mycorrhizal fungal (AMF) relationship has been verified for some important western coniferous species, such as incense cedar (*Calocedrus decurrens* (Torr.) Florin), coastal redwood (*Sequoia sempervirens*), and western redcedar (*Thuja plicata*). This study was designed to determine the response of incense cedar after soil fumigation with and without the addition of phosphorous fertilizer and a commercial mycorrhizal inoculant. Incense cedar performance was monitored in both the nursery and outplanted environments.

Methods

Nursery

Uniform nursery beds were fumigated at the USDA Forest Service J Herbert Stone Nursery in Central Point, Oregon, in fall 1990. Four replicate plots of 4 treatments were installed with 1.0 m (3.3 ft) buffers separating plots. Four plots (2.0 m long by 1.25 m wide [6.6 by 4.1 ft]) were randomly assigned 1 of 4 treatments before sowing incense cedar seeds. Treatments were as follows:

1. **MYCO/no P**—Propagules of *Glomus intraradices* were added at a rate of 12,000 propagules/m^2 (1,100 propagules/ft^2), and no phosphorous fertilizer was added.
2. **MYCO/P**—Propagules of *Glomus intraradices* were added at a rate of 12,000 propagules/m^2 (1,100 propagules/ft^2), and phosphorous fertilizer was applied at a rate of 0.02 kg P_2O_5/m^2 (200 lb/ac [224 kg/ha]).
3. **No MYCO/no P**—No *Glomus intraradices* and no phosphorous were added to the plot.
4. **No MYCO/P**—No *Glomus intraradices* was added to the plot and phosphorous fertilizer was applied at a rate of 0.02 kg P_2O_5/m^2 (200 lb/ac [224 kg/ha]).

Mycorrhizal inoculum containing spores and root fragments of *Glomus intraradices* was produced on an inert clay carrier and added to the seedbed plots at the time of sowing in April 1991. Mycorrhizal propagule densities were determined using the sugar centrifugation spore extraction method and clearing and staining of the colonized root fragment techniques.

Seedlings of all treatments were grown under standard 1+0 seedling culturing practices. In winter 1991, seedlings were evaluated for stem diameter, height, seedbed density, and percent mycorrhizal colonization. Seedlings were stored in coolers at 1 °C (34 °F) until outplanting.

Outplanting Sites

Outplanting sites were 2 clearcut sites in the Illinois Valley Ranger District of the Siskiyou National Forest of southwest Oregon. Seedlings were planted on a west-facing slope (Site 1) and a south-facing slope (Site 2) in the Wood Creek drainage and at a mean elevation of 480 and 420 m (1,575 and 1,380 ft), respectively. Slope steepness ranged from 25 to 50%. Soils were fine-loamy mixed mesic Ultic Haploxeralfs, formed in colluvium derived from metavolcanic parent material of 80 to 120 cm (31 to 47 in) depth. Coarse fragments in the surface soil averaged 35%. Annual precipitation averages 210 cm (83 in), with more than 90% of it falling between mid-September and mid-May.

Outplanting sites were clearcut in winter of 1990, broadcast burned in fall of 1991, and outplanted with nursery study seedlings in spring of 1992. The fall broadcast burn intensity was severe, as all surface litter and duff layers, downed woody material less than 20 cm (8 in), leaves, and needles were completely consumed by the fire. Following the burn, bare mineral soil was exposed on 70 to 80% of the 2 clearcut sites.

Naturally reoccurring clumps of pioneering hardwoods—primarily the arbutoid or ectomycorrhizal Pacific madrone (*Arbutus menziesii* Pursh), chinkapin (*Castanopsis chrysophylla* [Dougl.] A. DC.), tanoak (*Lithocarpus densiflorus* [Hook. & Arn.] Rehd.), and California black oak (*Quercus kelloggii* Newb.), and the AMF western poison oak (*Rhus diversiloba* T. & G.)—were widespread across the 2 clearcuts.

Outplanting Procedure—In April 1992, 4 planting blocks of 10 by 10 m (33 by 33 ft) were established at each of the 2 clearcut test sites. Seedlings were sorted on the landing before outplanting to assure seedlings of similar size would be outplanted for each treatment. Each block was located entirely on the same aspect and slope. Sixteen incense cedar seedlings from each nursery treatment were arrayed in a 4 by 4 pattern with 0.5 m (1.6 ft) spacing between seedlings and 1.0 m (3.3 ft) spacing between treatments.

Plastic netting was placed around seedlings following outplanting to reduce browsing by deer. The stem diameter, 1 cm (0.4 in) above the soil surface, was recorded for each seedling at outplanting time. Seedling survival, stem diameter, and leader growth were measured for all surviving seedlings 14 months following outplanting.

Mycorrhizal Colonization—On each site, 2 seedlings per treatment and per replication were randomly selected for mycorrhizal colonization percentage at the time of lifting and 14 months after outplanting. Root systems were extracted from soil, taken to the laboratory, and gently washed free of soil and extraneous material. Arbuscular mycorrhizal colonization was determined by cutting fine root samples into segments that would fit handily in small capsules used for clearing and staining. Roots were cleared in 10% KOH solution, steamed 72 hours, rinsed with tap water, transferred to 1% HCL solution for 30 minutes, then rinsed again with tap water. Cleared samples were transferred into a staining solution of 0.5% trypan-blue in lactoglycerol, steamed for 60 minutes, rinsed with tap water, and stored in refrigerated cold water until microscopic examination. Cleared and stained root segments from each capsule were examined and tallied for the presence of arbuscular spores, vesicules, and arbuscules of mycorrhizal fungi using a dissecting microscope and sub-sample with the compound microscope. Counts were tallied on a graduated Petri dish.

Statistical Analyses

A statistical randomized block design and the analysis was performed utilizing ANOVA and Tukey's multiple range testing. Comparisons of nursery seedling stem diameter, height, seedbed density, foliar phosphorous content, and mycorrhizal colonization data were performed. Similarly, comparison of seedling stem diameter, height, survival, and mycorrhizal colonization data were compared by treatment for each of the 2 clearcut test sites.

Residuals from the data on stem diameter, height, and mycorrhizal colonization were plotted to determine if a log-normal transformation was necessary to compensate for log-normally distributed values. This indeed was the case, so the data were accordingly transformed to produce a relatively normal distribution (Steel and Torrie 1960).

Results

Nursery

Seedling heights, stem diameters, seedbed densities, mycorrhizal colonization, and foliar phosphorus levels after lifting in winter 2001 are shown in Figures 1 through 5. MYCO/no P seedlings had significantly greater mycorrhizal colonization compared to all other treatments ($P < 0.05$). MYCO/P seedlings had significantly greater mycorrhizal colonization and height growth compared to No MYCO/P and No MYCO/No P treatments. MYCO/No P and MYCO/P seedlings had significantly greater foliar phosphorous levels compared to No MYCO/P and No MYCO/No P treatments.

Outplanting Sites

Figures 6 through 9 show seedling heights, stem diameters, survival, and mycorrhizal colonization after 14 months on the outplanting sites. MYCO/no P and MYCO/P seedlings had significantly greater mycorrhizal colonization, stem diameter, and height compared to No MYCO/P and No MYCO/no P treatments at both clearcut sites ($P < 0.05$).

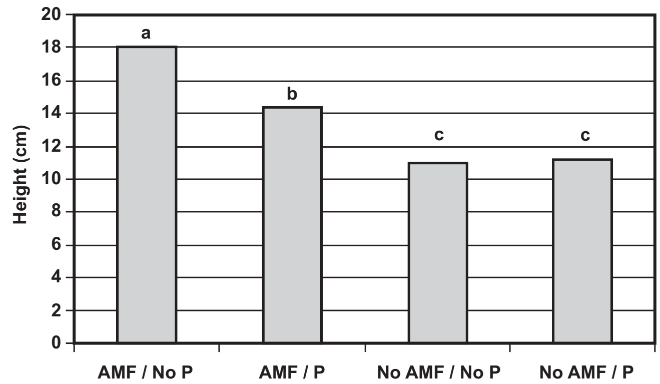

Figure 1—Height (cm) of *Calocedrus decurrens* seedlings grown at J Herbert Stone Nursery. Alpha symbols denote statistically significant results ($P < 0.05$).

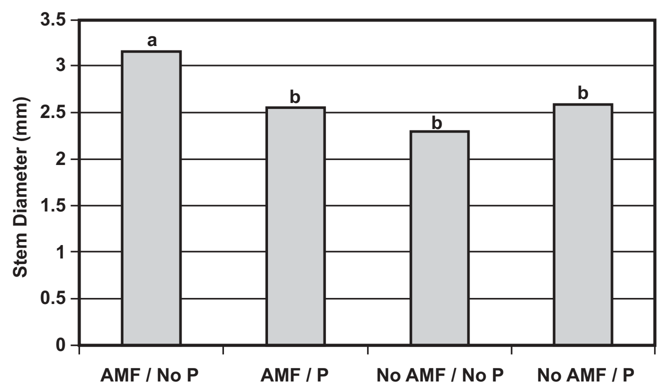

Figure 2—Stem diameter (mm) of *Calocedrus decurrens* seedlings grown at J Herbert Stone Nursery. Alpha symbols denote statistically significant results ($P < 0.05$).

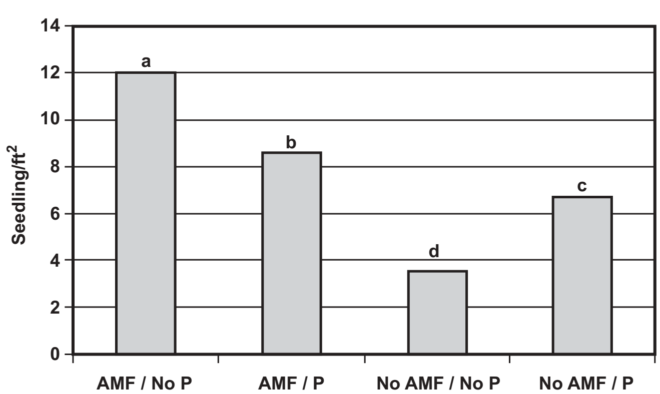

Figure 3—Seed bed density of *Calocedrus decurrens* seedlings grown at J Herbert Stone Nursery. Alpha symbols denote statistically significant results ($P < 0.05$).

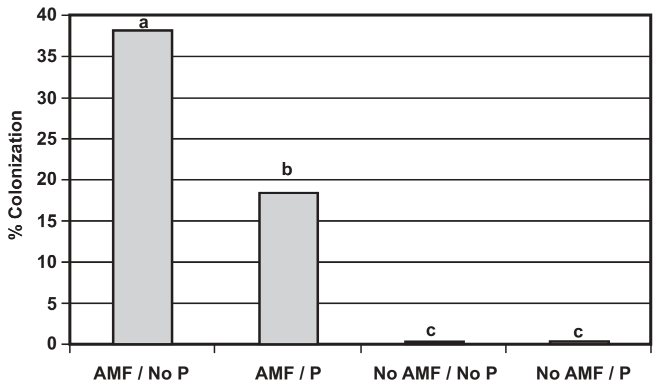

Figure 4—Percent mycorrhizal colonization of *Calocedrus decurrens* seedlings grown at J Herbert Stone Nursery. Alpha symbols denote statistically significant results ($P < 0.05$).

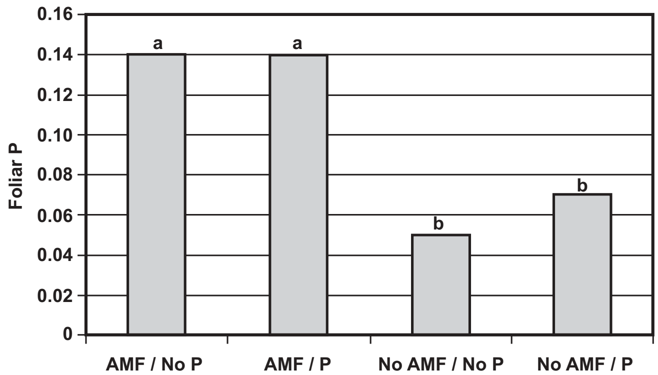

Figure 5—Percent foliar phosphorous (P) level of *Calocedrus decurrens* seedlings grown at J Herbert Stone Nursery. Alpha symbols denote statistically significant results ($P < 0.05$).

MYCO/no P seedlings had significantly greater survival percentage compared to No MYCO/P and No MYCO/No P treatments at both sites. MYCO/P seedlings did not survive significantly better than No MYCO/P seedlings at Clearcut Site 1 and No MYCO/no P seedlings at Clearcut Site 2. MYCO/No P had significantly greater height, survival, and mycorrhizal colonization than MYCO/P seedlings at Clearcut Site 1.

Discussion

In this study, both incense cedar growth and survival was influenced in both nursery and outplanting environments following AMF inoculation in fumigated nursery beds. Response was modified only slightly by the addition of phosphorous fertilizer at the nursery. Phosphorous addition in the MYCO/P treatment did significantly reduce the level of mycorrhizal colonization compared to the No MYCO/P treatment. However, even mycorrhizal colonization at 18% in the MYCO/P treatment was sufficient for the seedlings to significantly improve their growth performance

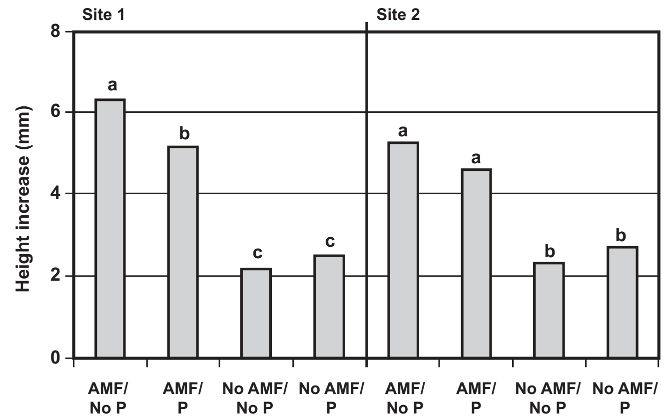

Figure 6—Height growth (mm) 14 months following outplanting. Alpha symbols denote statistically significant results ($P < 0.05$).

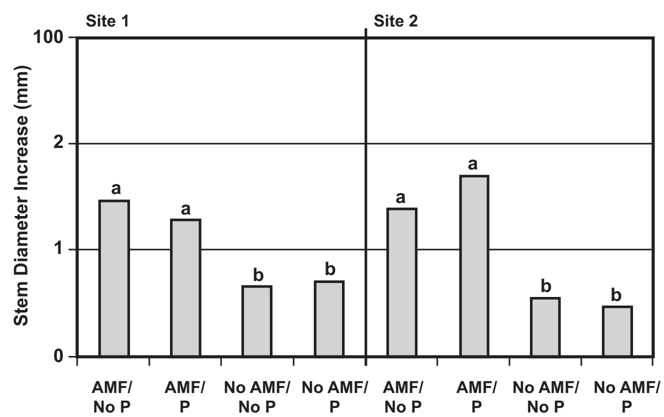

Figure 7—Stem diameter growth (mm) 14 months following outplanting. Alpha symbols denote statistically significant results ($P < 0.05$).

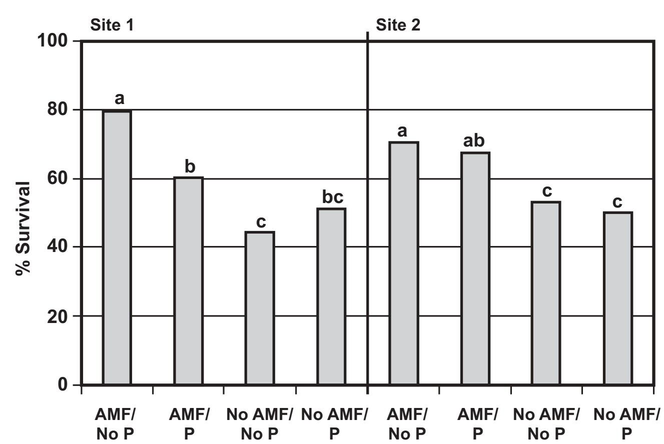

Figure 8—Survival percentage 14 months following outplanting. Alpha symbols denote statistically significant results ($P < 0.05$).

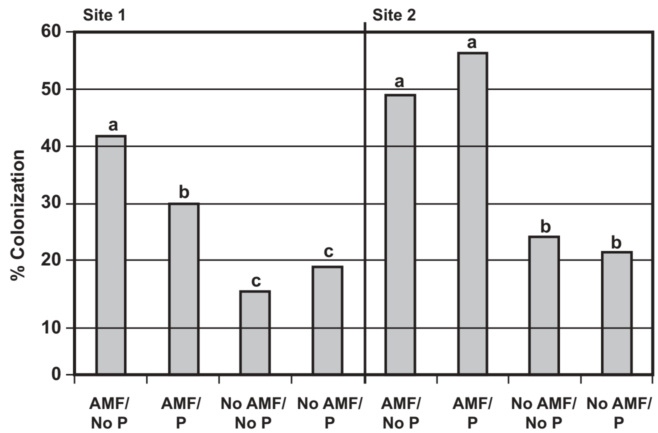

Figure 9—Mycorrhizal colonization percent 14 months following outplanting. Alpha symbols denote statistically significant results ($P < 0.05$).

and foliar phosphorous contents compared to the non-inoculated controls.

Young incense cedar seedlings inoculated and colonized with AMF clearly produce more uniform seedlings with improved height and bed density compared to No MYCO/P and No MYCO/No P seedlings. No MYCO/P and No MYCO/No P seedlings grew at lower densities and should have, as a result, greater stem diameter and height. In this study, the opposite was true—non-inoculated seedlings, which grew at low densities, had significantly less stem diameter and height.

Following fumigation, the addition of 0.02 kg P_2O_5/m^2 (200 lb/ac [224 kg/ha]) fertilizer should have provided enough phosphorous to the soil to saturate P-binding sites so that this essential nutrient would have been readily available to the roots. The bronzing effect and low foliar P level in the No MYCO/P treatment indicates that the higher level of phosphate was apparently inadequate for sufficient P uptake when incense cedar is non-mycorrhizal. The pre-existing soil phosphorous levels were adequate for MYCO/No P to have sufficient foliar P levels for adequate growth, even without the addition of P fertilizer.

At the seedling stage of plant growth, phosphorous uptake is presumably limited by the relatively small volume of soil occupied by root systems. AMF hyphae occupy a greater soil volume and produce specific enzymes for P extraction. In this study, the presence of AMF significantly improved seedling P nutrition at the nursery.

While phosphorous is generally very mobile in plant tissue, the only phosphorous reserve in young seedlings comes from the seeds themselves. As seed reserves become exhausted, the mycorrhizal association for P uptake is critical. Young seedlings, therefore, may be more responsive to mycorrhizal colonization than older plants. Although both young and old plants require and benefit from the mycorrhizal association, the survival and growth response may be more dramatic for younger plants because of their undeveloped root systems.

High levels of soil phosphorous have been shown to reduce or eliminate mycorrhizal colonization of conifer species (Harley and Smith 1983). Kough and others (1985) found, in a greenhouse study, that AMF-inoculated western redcedar, incense cedar, coastal redwood, and giant sequoia (*Sequoiadendron giganteum*) seedlings produced 100 to 2,000% more biomass than non-inoculated seedlings at low P (11 ppm), and from equality to a 500% increase at higher P (43 ppm). In their study, AMF inoculation enhanced seedling uniformity and size in all the tree species. Our results with incense cedar support their findings in the more operational environments of a production nursery and reforestation sites.

The increased survival and size of seedlings colonized by AMF mycorrhizae in our study has been reported on other host plants (Cooper 1981; Biermann and Linderman 1983; Kough and others 1985). The economic benefit after fumigation is clear—increased size and higher seedbed densities in the mycorrhizal-treated beds means more seedlings acceptable for outplanting.

At outplanting sites 1 and 2, results paralleled those at the nursery. MYCO/no P and MYCO/P seedlings grew better compared to No MYCO/P and No MYCO/No P seedlings. At the clearcut Site 1, however, the higher mycorrhizal colonization of MYCO/no P cedar seedlings at outplanting apparently improved their survival and height growth when compared to MYCO/P seedlings. Numerous other studies have shown the effectiveness of AMF in promoting plant nutrition and establishment on tree hosts (Graham and others 1982; Furlan and others 1983; Amaranthus and Trappe 1993; Pattinson 2001a).

Still other studies have examined the use of AMF inoculum to encourage the re-establishment of postfire native vegetation (Bellgard and others 1994; Rashid and others 1997; Pattinson and others 2001a,b). This study further supports the use of AMF inoculum on disturbed sites to encourage plant establishment and early conifer growth.

Timber harvest and site preparation are the 2 most common and widespread deliberate forest activities in the Pacific Northwestern United States. They significantly alter both the above and below ground environments. The outplanting test sites chosen for this study were severely disturbed by clearcutting and the intense fire that resulted from the fall prescribed burn, which likely reduced indigenous AMF populations. Other studies have shown reductions in AMF activity following vegetation removal and intense fire.

Fourteen months after outplanting, the No MYCO/P and No MYCO/No P groups still had significantly lower mycorrhizal colonization and less growth than MYCO/P and MYCO/No P treatments. The 2 clearcut sites were burned according to management prescription, and the intensity of the fire likely reduced the mycorrhizal colonization potential of the sites. Recent studies have examined the impact of wildfire and post-fire reestablishment (Vilarino and Arines 1991; Amaranthus and Trappe 1993; Bellgard and others 1994; Amaranthus and others 2004a). This study's data indicate the 2 clearcut and burned outplanting sites had lost their ability to rapidly form mycorrhizae for outplanted seedlings. Where the mycorrhizal forming potential of a site has been reduced, mycorrhizal inoculation following fumigation may allow seedlings to more rapidly acquire site resources in the outplanted environment.

Many foresters have observed a significant lag in the growth of cedar seedlings following outplanting. In this study, mycorrhizal-inoculated incense cedar seedlings grew more rapidly in the field than non-inoculated nursery seedlings, and thus may be a vital tool to encourage rapid growth of AMF host seedlings.

Summary

Mycorrhizal inoculation with *Glomus intraradices* following fumigation of nursery soils greatly enhanced *Calocedrus decurrens* performance at both the nursery and outplanting sites. The response was modified only slightly by the addition of phosphorous fertilizer at the nursery. Phosphorous addition in the MYCO/P treatment significantly reduced the level of mycorrhizal colonization compared to the No MYCO/No P treatment. However, even with the additional phosphorus treatment at the nursery, the seedlings averaged 18% mycorrhizal colonization root system performance and foliar phosphorous contents when compared to the non-inoculated controls.

Young incense cedar seedlings inoculated and colonized with AMF clearly produced more seedlings with improved height and stem diameter compared to No MYCO/P and No MYCO/No P seedlings. After 14 months planted in the clearcut sites, incense cedar seedlings not inoculated at the nursery still had significantly less mycorrhzal colonization compared to nursery inoculated seedlings.

Increased nursery survival and seedling size are tangible economic returns for the production nursery. Increased field survival and growth are important goals for foresters on difficult sites. Nursery practices, such as using fumigants, may produce non-mycorrhizal seedlings that perform poorly upon outplanting, especially on sites where the period for seedling establishment is limited and native mycorrhizal colonization potential is low.

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Restoring Native California Oaks on Grazed Rangelands

Douglas D. McCreary
Jerry Tecklin

Douglas D. McCreary is Program Manager, Integrated Hardwood Range Management Program, Department of Environmental Science, Policy and Management, UC Berkeley, 8279 Scott Forbes Road, Browns Valley, CA 95918; telephone: 530.639.8808; e-mail: ddmccreary@ucdavis.edu. Jerry Tecklin is Staff Research Associate, retired, 8279 Scott Forbes Road, Browns Valley, CA 95918; e-mail: jetecklin@ucdavis.edu

In: Dumroese, R. K.; Riley, L. E.; Landis, T. D., tech. coords. 2005. National proceedings: Forest and Conservation Nursery Associations—2004; 2004 July 12–15; Charleston, NC; and 2004 July 26–29; Medford, OR. Proc. RMRS-P-35. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Abstract: Efforts to regenerate oaks on California's oak woodlands often must address how to establish seedlings in areas grazed by livestock. Research indicates that damage to young oak seedlings from cattle varies by season, with less damage during the winter when deciduous oaks do not have leaves. While exclusion of cattle from planted areas does result in reduced damage, the buildup of thatch or dead grass following livestock removal can promote an increase in damage to seedlings from voles (*Microtus californicus*) and grasshoppers (*Melanoplus devastator*). The most effective method we have found to simultaneously grow oaks and cattle incorporates individual tree protectors called "treeshelters." Limited research suggests that treeshelters protect seedlings from damage from most animals, including livestock. Cattle will browse the shoots of seedlings growing up and out the tops of 1.3-m (4-ft) shelters, but that damage is rarely lethal and has relatively little long-term impact to oak seedling establishment. Unprotected oak saplings appear relatively resistant to cattle damage if they are at least 2 m (6.5 ft) tall. Together, these findings suggest that cattle and oaks can be raised simultaneously if sufficient protective measures are taken to prevent damage to young plants.

Keywords: *Quercus*, treeshelters, livestock, regeneration, woodlands

Introduction

California's oak woodlands, also known as hardwood rangelands, cover approximately 3 million ha (7.4 ac), or 10% of the State. These areas have an overstory of trees, predominantly in the oak genus (*Quercus* spp.), and an understory of exotic annual grasses and forbs, with occasional native perennial grasses. Oak woodlands provide a wide range of critical values and services including forage for livestock, important wildlife habitat, recreation, beautiful scenery, and watershed protection. Since European settlement, these lands have been managed primarily for livestock production (Figure 1).

For nearly a century, there has been concern that several of California's 20 native oak species are not regenerating adequately (Jepson 1910). Such concern was partially responsible for the establishment of the Integrated Hardwood Range Management Program (IHRMP) in 1986, a cooperative effort between the University of California, the California Department of Forestry and Fire Protection, and the California Department of Fish and Game to promote oak woodland conservation (Standiford and Bartolome 1997). Evidence indicating that there is an "oak regeneration problem" in California has been based largely on observations of a paucity of young seedlings and saplings in the understories of existing oak stands. Describing the foothill woodland in the Carmel Valley, White (1966) stated that "A prevailing characteristic . . . is the lack of reproduction . . . with very few seedlings." Bartolome and others (1987) also concluded that "current establishment appears insufficient to maintain current stand structure for some sites." And Swiecki and Bernhardt (1998) reported that of 15 blue oak locations evaluated throughout the State, 13 were losing stand density at the stand level due to unreplaced mortality.

The species that are having the most difficulty regenerating are all members of the white oak sub-genera of *Quercus*, and include blue oak (*Quercus douglasii*), valley oak (*Q. lobata*), and Engelmann oak (*Q. engelmannii*) (Muick and Bartolome 1987; Bolsinger 1988). Blue and valley oak are endemic to the State, while Engelmann oak, which actually has a far narrower distribution range than the other 2 species, does extend into Baja California (Griffin and Critchfield 1972). Concern about poor

Figure 1—The vast majority of oak woodlands in California are privately owned, and the primary economic activity on these lands is livestock grazing.

regeneration has been responsible for the initiation of a wide range of research during the last 2 decades aimed at both understanding the major factors contributing to regeneration failures, and developing strategies to overcome obstacles to successful regeneration. Research has addressed a wide array of subjects, including acorn collection, storage and handling, seedling propagation methods, and techniques for planting, protecting, and maintaining seedlings in the field (McCreary 2001).

Grazing Experiments

The University of California Sierra Foothill Research and Extension Center (SFREC) is a 2,300-ha (5,700-ac) field station in the low-elevation foothills of Yuba County, CA, that supports a large research cattle herd. It also provides land and facilities for a variety of natural resource-related research. Part of this research has been aimed at developing practical, low-cost procedures for restoring oaks. Several of these oak-regeneration studies have been conducted in areas grazed by cattle, with one of the objectives being to identify how oaks can be established in grazed pastures without removing these lands from livestock production. That is, how can cattle and oaks be raised together? This is important because approximately 80% of the oak woodlands in California are privately owned, and the primary use of these properties is livestock production (Bolsinger 1988).

Timing of Grazing Study

In 1989, a UC Davis graduate student named Lillian Hall initiated an experiment at the SFREC to evaluate how planted oak seedlings fare in pastures where cattle have access (Hall and others 1992). She planted 1-year-old blue oak seedlings in pastures grazed by cattle at different stock intensities, and included a control where cattle were excluded. She found that damage to seedlings was significantly less in the winter and fall when the deciduous oaks did not have foliage and were apparently less appetizing to the cattle. Cattle did not seem to seek out or prefer young oaks. However, in the spring green-forage season, they appeared drawn to clover patches near seedlings and browsed the oaks in the process. Heavy damage to seedlings in the summer at all cattle densities probably resulted from the fact that the young oaks were often the only green vegetation in the grazed pastures, and were therefore more palatable than the dry annual grasses. Within each season, total damage also increased with increasing stock density.

Riparian Restoration Planting

In 1994, we initiated a study at the SFREC to evaluate alternative practices for restoring woody plants along a perennial stream that had been cleared of woody vegetation in the late 1960s. As a result of this clearing, there were few trees or shrubs adjacent to the stream, and the predominant vegetation included broadleaved cattail (*Typha latifolia*), rushes (*Juncus* spp.), and sedges (*Carex* spp.). This study evaluated 3 different methods for restoring woody plants along a 600-m (1,970-ft) section of the stream. Treatments including fencing (cattle only excluded, deer still had access), protection of individual plants with treeshelters, and a control consisting of planting, but no protection. Treeshelters are rigid, translucent double-walled plastic tubes that are placed over individual seedlings, protecting them from a variety of animals, including both deer and cattle. They also stimulate accelerated shoot growth of the seedlings growing inside the tubes (McCreary and Tecklin 2001). However, in grazed pastures, it is critical that shelters be secured with heavy metal fence posts so that they are not bent over or broken as a result of cattle rubbing on them.

Each of the protection treatments was replicated 5 times in 30-m (100-ft) stretches of the stream, and in each replication we planted 70 total seedlings and cuttings, including Fremont cottonwood (*Populus fremontii*), Arroyo willow (*Salix lasiolepis*), narrow-leaved willow (*S. exigua*), blue oak, valley oak, and interior live oak (*Q. wislizenii*). During each year of the study, cattle grazed the area where the plantings were located. Generally 30 to 60 head were placed in the 30-ha (74-ac) pasture for a 3- to 6-week period. All plantings were evaluated for 4 years, and each plant was assessed annually for survival and year-end height.

Results of this study (McCreary 1999) indicated that successful restoration of the oaks required protecting individual seedlings with treeshelters. After 4 years, average survival in treeshelters for all oak species combined was 58%, while oaks in fenced plots had only 5% survival, and unprotected seedlings in control plots had less than 1% survival. Oak seedlings that did survive in treeshelters grew quite vigorously, with an average height of nearly 2 m (6.5 ft) after 4 years.

Ungrazed and Grazed Plots

In 1997, a 2-ha (5-ac) oak planting that had been initially established at the SFREC in 1990 (Tecklin and others 1997) was divided in half, with one-half of the plot exposed to limited grazing for approximately 5 weeks per year. The blue oak seedlings in the plot varied greatly in size because they had been established in different years, and some had been protected with treeshelters and others had not. As a result, plants varied from a few cm tall—usually resprouts after seedlings had been girdled at the ground—to healthy, robust saplings that had grown above the tops of the 1.3-m (4-ft) treeshelters (Figure 2). After 3 years, plants inside grazed plots were compared to those outside (Tecklin and others 2002). There was no increase in mortality resulting from the grazing, but there were differences in seedling condition between grazed and ungrazed plots. Unprotected seedlings in ungrazed plots had significantly more vole damage than unprotected seedlings in grazed plots (52% versus 0%). This was due to the fact that, in ungrazed plots, there was a large increase in dead thatch on the surface of the ground. Such thatch is ideal habitat for voles and resulted in higher population levels and much more bark stripping and girdling of oak seedlings. For the oaks protected with treeshelters, however, the results were almost the opposite. That is, there was evidence of far greater animal damage in the grazed plots—the animals in this case being cattle—while there was virtually no animal damage to the oaks inside treeshelters in the ungrazed plots. Damage in the grazed plot consisted of clipping of the shoots that were above the tops of the 1.3-m (4-ft) shelters, resulting in noticeably sparser crowns. Some of the shelters were also partially bent over from cattle rubbing (though all were secured with heavy metal fence posts), but no seedlings were killed. There were differences in height and basal diameter growth between sheltered plants in grazed and ungrazed plots, with those in grazed plots growing less. However these differences were relatively small and seedlings that were browsed were not seriously damaged.

Figure 2—Treeshelters are double-walled plastic tubes that have been successfully used to protect outplanted oak seedlings from a variety of animals including cattle.

Study to Evaluate Cattle Impacts to Various-Sized Oaks

Another study to evaluate the impacts from cattle to a range of sizes of oaks was commenced in 2003. This study used a blue oak planting that was established at the SFREC between 1988 and 1990 by Ted Adams (Adams 1995), a Wildland Specialist at UC Davis. He had established several hundred oaks inside a 0.22-ha (0.5-ac) plot, fenced to exclude both deer and cattle. At the initiation of our study, there were a total of 144 living seedlings and saplings that ranged in height from 43 cm to 4.3 m (17 in to 14 ft). We divided this plot in half and opened half of it to cattle grazing. This plot was within a 40-ha (100-ac) pasture that was grazed for 6 weeks in 2003 by 50 cows and 49 calves. Prior to removing the fence for half of the plot, we assessed each seedling in both plots for height, basal diameter, and crown spread.

After a full season of grazing, we assessed each oak for the same variables we recorded before the grazing began. During this second assessment, we also noted obvious cattle damage, as well as mortality if it had occurred. Seedlings and saplings that remained inside the fenced portion of the plot grew significantly taller than those exposed to cattle (22 cm versus 8 cm [9 in versus 3 in]). Although only 1 seedling was killed in the grazed portion of the plot, the cattle did severely impact a number of the plants by browsing and rubbing. However, damage from cattle varied greatly depending on seedling initial size. Oaks less than 2 m (6.5 ft) tall were far more likely to suffer damage than plants taller than this. Of the 79 surviving oaks in the grazed portion of the plot, 11 lost more than 15 cm (6 in) in height. These were all less than 2 m (6.5 ft) tall at the start of the study. Furthermore, the average height gain during the 2003 growing season of the 46 plants greater than 2 m (6.5 ft) at the start of the study was 30 cm (12 in). In contrast, the 33 plants less than 2 m (6.5 ft) at the commencement of grazing lost an average of 22 cm (8.6 in) in height. Although this study has only been in place for a single year, and we plan to maintain it for at least 2 more years; initial results indicate that there is a threshold height above which oaks are large enough to withstand cattle damage. It appears that this threshold is near 2 m (6.5 ft) (Figure 3).

Summary

Native California oaks can be established in pastures grazed by cattle, but it is important to protect individual seedlings from browsing and rubbing until they are approximately 2 m (6.5 ft) tall. Excellent protection can be achieved by placing individual 1.3-m (4-ft) tall treeshelters around young seedlings. These devices not only protect seedlings from a variety of potentially damaging animals, including cattle, but also stimulate rapid aboveground growth. However, where livestock are present, it is critical that shelters be well secured to heavy metal fence posts to ensure they remain upright and are not bent over from cattle rubbing. Seedlings growing up and out of the tops of 1.3-m (4-ft) shelters are vulnerable to livestock clipping of the exposed shoots; in moderately grazed pastures, such damage appears to have little long-term impact on seedling survival or growth.

Figure 3—Oak seedlings that are at least 2 m (6.5 ft) tall appear to be large enough to withstand injury from cattle.

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Variation in Nutrient Release of Polymer-Coated Fertilizers

Douglass F. Jacobs

Douglass F. Jacobs is Assistant Professor with the Hardwood Tree Improvement and Regeneration Center, Department of Forestry and Natural Resources, Purdue University, West Lafayette, IN 47907; telephone: 765.494.3608; e-mail: djacobs@purdue.edu

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Abstract: Polymer-coated fertilizers (PCF) are used primarily in horticultural plant production. However, interest in using these fertilizers in forest tree nurseries has increased over the last decade. Compared to immediately-available forms of fertilizer and other controlled-release fertilizer types, PCF tend to release nutrients in a relatively consistent flow over time. This helps to improve efficiency of fertilizer use. Nutrient release from PCF is primarily dependent on media temperature; an estimated timeframe for nutrient release at a specific temperature is provided by the manufacturer. Although many different products fall into the general category of PCF, the actual polymer material used varies among products. This affects the degree to which nutrients are released over time. Additionally, timeframes for nutrient release are simply estimates provided by the manufacturer based on lab results, and actual release under operational conditions may deviate considerably from these estimates. There is also considerable variation in release of individual nutrient ions over time from PCF. For instance, many products release a large percentage of available nitrogen soon after application, while release of phosphorus is delayed. Because timing of nutrient release can be critical to successfully using PCF in forest tree nurseries, differences among products should be understood by nursery growers when incorporating various types of PCF into production.

Keywords: controlled-release fertilizer, seedling nutrition, electrical conductivity, nutrient leaching, Osmocote®, Nutricote®, Polyon®

Introduction

Polymer-coated fertilizers (PCF) have been in use within the horticultural industry for decades. These fertilizers represent the most technically advanced state of the art among controlled-release fertilizers (CRF) in controlling product longevity and efficiency of nutrient delivery for plant uptake (Goertz 1993), and PCF comprise the majority of CRF used in horticultural plant production (Bunt 1988; Goertz 1993; Huett and Gogel 2000). Compared to other types of CRF, these fertilizers tend to provide a more gradual and consistent nutrient release pattern with release rates ranging from about 3 months to nearly 2 years. Other types of CRF often provide only nitrogen, but PCF may be blended to provide a balance of all macro- and micronutrients. An advantage of PCF over conventional water soluble fertilizers (that is, fertigation) is that a single application of PCF can supply plants with extended nutrient availability, eliminating the need for labor costs associated with repeated fertilizer application.

Due to the costs of the polymer coating, PCF have traditionally been restricted to relatively high value applications. However, there has been increased interest in mixing PCF into container media in forest tree nurseries. This has become standard operation for a significant portion of seedlings grown by some private companies. Additionally, clients occasionally request that PCF be incorporated into the media of seedlings grown on contracts. In theory, the PCF should begin to release nutrients during nursery propagation, and products with a longer timeframe for nutrient release may continue to provide elevated levels of nutrients to seedlings following outplanting (Jacobs and others 2003a).

Nutrient release from prills of PCF (Figure 1) occurs by diffusion through a semi-permeable membrane. The mechanism of nutrient release is accomplished in 2 stages (Gambash and others 1990). Soon after application and exposure to moisture, water vapor infiltrates into the fertilizer prill and condenses on the soluble fertilizer salt, creating an internal osmotic pressure gradient. The elevated pressure within the prill then allows the fertilizer salts to leak into surrounding media. A

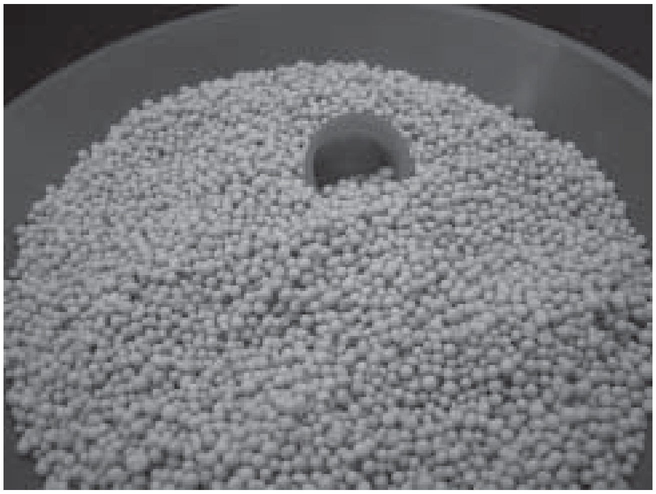

Figure 1—Prills of polymer-coated fertilizer.

given proportion of total nutrients (~20%) may never release from prills of PCF, because the pressure within the prill decreases as the majority of nutrients are released. Manufacturers are able to adjust release rates by changing the physical characteristics of the coating, either the coating thickness or chemical composition of the polymer itself (Goertz 1993).

As many forest tree nurseries are beginning to integrate PCF into production, questions have arisen as to precise mechanisms of how these products release different nutrients and potential variation among products. Using PCF in container media has led to dramatic improvements in both quality of forest tree seedlings following nursery growth and field performance (Nursery Technology Cooperative at Oregon State University, unpublished data). However, some growers have experienced problems with excessive release of fertilizer nutrients into growing media from PCF, which may cause damage to plant roots (Jacobs and others 2003b). Additionally, release of nutrients (for example, ammonium) late in the growing season may promote undesired shoot growth during dormancy induction (Landis and others 1989). Growers must understand that when using PCF, precise control of nutrient supply to plants is reduced compared to conventional water soluble fertilizer inputs. Furthermore, it is important to keep in mind that PCF products currently available on the market were generally not designed specifically for use with forest tree seedlings, but rather for crops more commonly produced in the horticultural industry.

It is therefore important to be well aware of nutrient release characteristics of PCF and potential differences among comparable products. Thus, the objectives of this paper are to: (1) explain factors controlling the rate and pattern of nutrient release from PCF, (2) describe variation in release of individual nutrient ions from PCF, (3) compare differences in coating technology among varying products of PCF, and (4) synthesize the current literature regarding variation in nutrient release among different products of PCF.

Rate and Pattern of Nutrient Release

Two terms that are helpful when examining how PCF release nutrients are the rate and pattern of nutrient release. Rate refers to the total quantity of nutrients released over the entire time period; pattern refers to the periodic distribution of nutrient release at specified time intervals throughout the designated release period. Manufacturers of PCF generally strive to produce a product that begins to release nutrients soon after application and provides a consistent flow of nutrients through the duration of the designated release period. Hence, the rate would be delivered in a pattern of equal distribution over the release timeframe.

In forest tree nurseries, it might be preferable if nutrients were delivered in an exponentially increasing manner (Timmer 1997) to better match supply with plant demand. There is potential for this pattern of nutrient release to be achieved with products characterized by a release period of 5 to 6 months or more. However, the actual pattern of nutrient release of some PCF types may be to dispel a large portion of nutrients in the early stages of the designated release period when plant demand is low. For instance, in a study where Osmocote® and Nutricote® (3- to 4-month release) were tested, the most rapid nitrogen (N) and potassium (K) release occurred within the first 2 weeks after potting, resulting in significant nutrient leaching and poor efficiency of fertilizer use (Huett 1997a,b).

The major environmental factor controlling the pattern of nutrient release from PCF is media temperature (Kochba and others 1990). Soil moisture percentage within the range typically maintained in container seedling production has a relatively minor influence on nutrient release from PCF. Kochba and others (1990) reported no significant difference in patterns of nitrate released when soil moisture varied between 50 to 100% of field capacity (Figure 2). In contrast, nutrient release from PCF may increase dramatically as media temperatures rise (Kochba and others 1990; Huett and Gogel 2000) (Figure 3). Kochba and others (1990) studied nutrient release behavior of PCF and, in one instance,

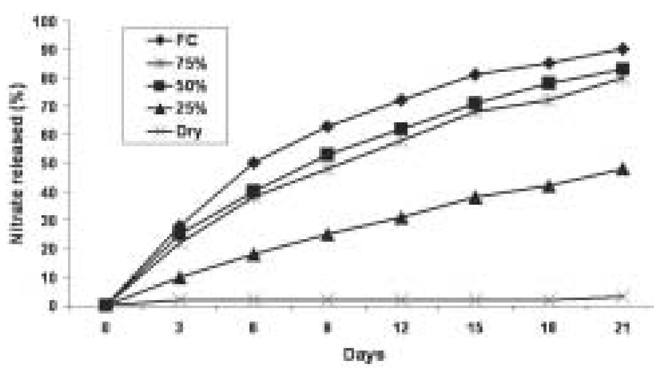

Figure 2—Release of nitrate from polymer-coated fertilizer based on media moisture content (adapted from Kochba and others 1990).

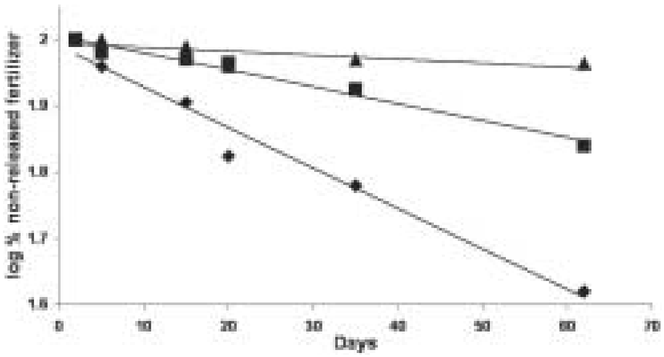

Figure 3—Release of nutrients from polymer-coated fertilizer based on media temperature (adapted from Kochba and others 1990).

reported a doubling of nutrient release when temperatures were increased by 10 °C (18 °F). Release rate of N, P, and K in a variety of Osmocote®, Polyon®, and Nutricote® fertilizers increased by 13 to 19% with a 10 °C (18 °F) rise in temperature (Huett and Gogel 2000).

Manufacturers provide estimates for duration of nutrient release from products of PCF. These estimates are generally based on controlled laboratory trials where total fertilizer released (by weight) is determined under constant temperature conditions, typically ranging from 21 (most common) to 25 °C (70 to 77 °F) (Goertz 1993). Actual rates of nutrient release under operational conditions may vary considerably from these estimates (Bunt 1988), as greenhouse temperatures may fluctuate dramatically both diurnally and seasonally. Thus, it is unlikely that PCF will conform closely in operation to estimates provided by manufacturers. In fact, release may be much slower (cool temperatures) or faster (warm temperatures) than expected. This suggests that growers should consistently monitor electrical conductivity (either of leachate or media) and supplement with fertigation or leach as necessary.

Variation in Release of Individual Nutrient Ions

In any fertilization program, it is important to understand the concept of nutrient balancing. This concept simply emphasizes that more important than absolute quantities of nutrients in the media is the balance of the supply of one nutrient to another. Ingestad (1977) proposed an optimum ratio of 100:50:15:5:5 for nitrogen (N) relative to potassium (K), phosphorus (P), calcium, and magnesium. This ratio seems to hold constant over a range of plant species. When nutrient ratios become imbalanced, plant development is likely to be limited by the nutrient in shortest supply.

Because container propagation of forest tree seedlings generally incorporates a peat-vermiculite media with low inherent fertility, most nutrients under these cultivation systems are supplied through external fertilizer inputs (Landis and others 1989). Fertigation with water-soluble fertilizers generally provides an adequate balance of both macro- and micronutrients. Because PCF also tend to contain a measured balance of most or all plant essential mineral nutrients, growers generally assume that a properly balanced nutrient ratio would be provided by PCF. However, there appears to be considerable variation in release of individual nutrient ions from PCF.

A field study examining release of individual nutrient ions from different Polyon® products with a range of estimated times for nutrient release found that ammonium (NH_4) and nitrate (NO_3) released 85 to 91% and 71 to 85%, respectively, of available nutrients during an approximately 15-month period (Nursery Technology Cooperative at Oregon State University, unpublished data). However, release of phosphate (P_2O_5) was found to be only 19 to 37% of original composition during the release period. Ranking of macronutrient release was NO_3 > NH_4 > K > sulfur > magnesium > P. Release of micronutrients (that is, iron, manganese, zinc, and molybdenum) decreased very little from initial contents. Similarly, it was reported that P released at 60 to 80% of the N and K rate in Nutricote® and Osmocote® (Handreck 1997); and Huett and Gogel (2000) found the time-to-release in order of N > K > P.

The apparent lag in release of P as compared to other macronutrients from PCF could cause potential for concern if this created an imbalance in plant nutrient ratios. It is likely that mechanisms for inefficient release of P may be related to the tendency of P to adsorb to other mineral nutrients (for example, iron and aluminum) to form insoluble metal phosphates. This can be of particular relevance at extreme (that is, high or low) pH values, which may sometimes be induced locally through rhizosphere acidification following root uptake of NH_4. Release of P may be further reduced by its very low soil mobility. Thus, it is possible that much of the P contained within prills of PCF is either bound chemically or does not move beyond the immediate vicinity of the prill. This implies that P should be in greater quantity in PCF than N. However, most formulations of PCF have a 3 to 1 or greater ratio of N to P in the formulation. There is potential that this imbalance could limit seedling morphological and physiological development due to a low P to N ratio, though few published accounts have specifically addressed this issue. Furthermore, it has been suggested that for (at least) growth of forest tree seedlings, response is largely driven by fertilizer N content, with specific formulations of other mineral nutrients having little additional influence (van den Driessche 1997).

Polymer Coating Technology

Many different PCF are marketed for use in container production of forest tree seedlings. Perhaps the most common 3 product types are Nutricote®, Osmocote®, and Polyon® and this section focuses on them. Though all classified under the general category of PCF, the actual coating technology varies among these products. The following section briefly describes coating technology of these products as presented in Goertz (1993).

Nutricote® (Chisso-Asahi Fertilizer Company, Ltd, Tokyo, Japan) employs thermoplastic resins (polyolefin, poly [vinylidene chloride], and copolymers) as coating materials. Thermoplastic resins are highly impermeable to water. Thus, release controlling agents (ethylene-vinyl acetate and surfactants) are added to the coating to attain desired diffusion character. Coating thickness is the same for all products, and the amount of added release controlling agents determines nutrient release rate. Manufacturers have attempted to minimize the effect of temperature on patterns of nutrient release by dispersing mineral fillers into the coating.

The coating technology in Osmocote® (OM Scotts Company, Marysville, OH) was developed in the 1960s, and this coating is classified as a polymeric resin. The coating process involves coating a soluble fertilizer core with a thermoset copolymer of dicyclopentadiene and a glycerol ester (linseed oil) dissolved in an aliphatic hydrocarbon solvent. The coating is applied in several layers, and coating thickness controls the pattern of nutrient release. Product longevities currently range from as little as 3 to 4 months to as long as 14 to 16 months.

As of 1988, Polyon® (Pursell Industries, Inc., Sylacauga, AL) employs a reactive layer coating (RLC) process which polymerizes 2 reactive monomers as applied to the fertilizer substrate in a continuous coating drum, forming an ultra-thin polyurethane membrane coating. Apparently, the efficiency of the RLC process allows for somewhat lower production costs than many other PCF.

Variation in Nutrient Release Among PCF

Despite equivalent estimated times for nutrient release, different product types of PCF may have highly variable temporal patterns of nutrient release. Patterns of nutrient release among different products have been reported from laboratory experiments conducted under controlled temperatures (Lamont and others 1987; Cabrera 1997; Huett and Gogel 2000). Cabrera (1997) studied nutrient release behavior of 7 different PCF (each with an 8- to 9-month release period) over a 180-day experimental period. Osmocote® $24N:4P_2O_5:8K_2O$ (High-N) and Polyon® $25N:4P_2O_5:12K_2O$ exhibited a nutrient leaching pattern that closely followed changes in mean ambient daily temperatures, while Nutricote® $18N:6P_2O_5:8K_2O$ showed a more stable leaching pattern over a wider range of temperatures (Figure 4). The ability of the Nutricote® product to buffer against fluctuations in temperature may be partly a function of variation in coating technology, as described above.

Nutrient longevities (to 90% nutrient recovery) of Nutricote®, Osmocote®, and Polyon® were also studied under controlled conditions by Huett and Gogel (2000) at either 30 or 40 °C (86 to 104 °F) media temperature. They found that longevities of all formulations were considerably shorter than release periods designated by manufacturers. When examining 8- to 9-month longevity products, the general ranking of weeks to 90% recovery of N, K, or P was Nutricote® > Polyon® > Osmocote® regardless of media temperature (Figure 5).

Based on results described above from Cabrera (1997) and Huett and Gogel (2000), the tendency would be to assume that among products with comparable designated release periods, Nutricote® would release over a longer timeframe and be more resistant to fluctuations in media temperature than Polyon® or Osmocote®. However, this does not appear to always necessarily hold true. Huett and Gogel (2000) reported that when comparing Polyon® and Osmocote® (each with a 5- to 6-month release) with 140-day Nutricote®, longevity of N, P, and K was substantially less for Nutricote® than the other 2 products (Figure 6). Longevity of Polyon® was again greater than for Osmocote® (Figure 6).

Reports of nutrient release among comparable products of PCF are helpful in predicting how forest seedlings might respond to application of these products in container media. However, it should be noted that documented release patterns under controlled conditions often show poor correlation with operational plant growth, likely due to interactions between the fertilizer and growing system (Bunt 1988).

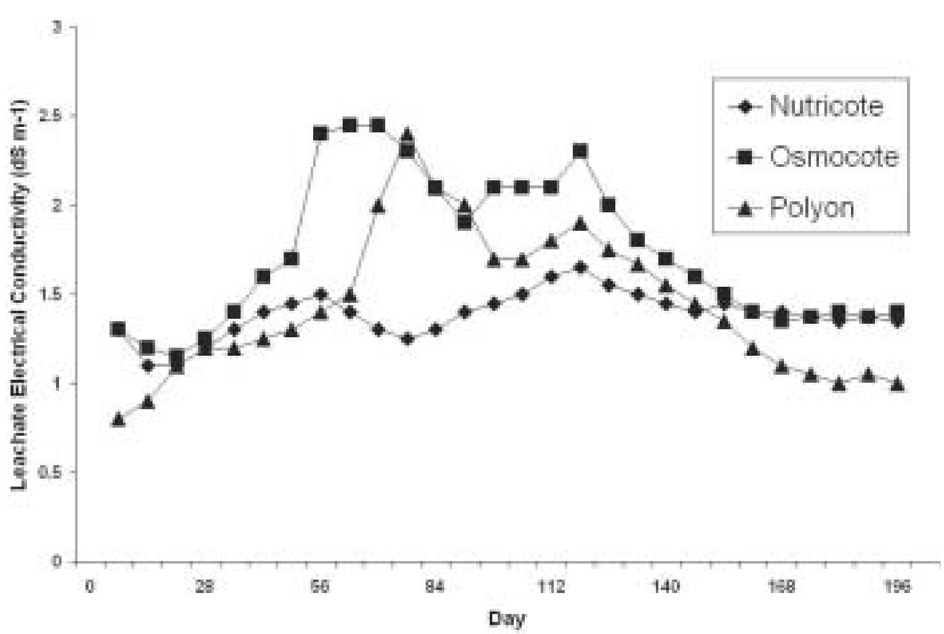

Figure 4—Variation over time in nutrient release (measured by electrical conductivity) from 3 different polymer-coated fertilizer products (adapted from Cabrera 1997).

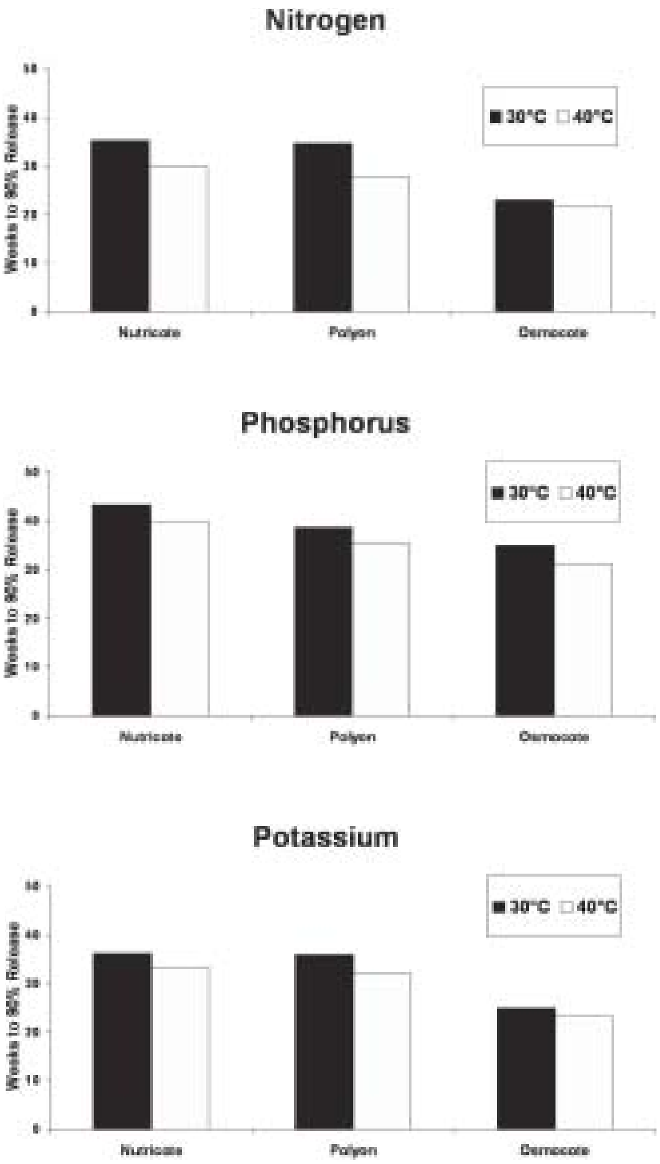

Figure 5—Weeks to 90% fertilizer nutrient recovery from 3 different polymer-coated fertilizer products, each with an estimated 8- to 9-month release timeframe, at either 30 or 40 °C media temperature (adapted from Huett and Gogel 2000).

Though increasing in recent years, relatively few research studies have examined how variation in nutrient release among comparable PCF products affects forest seedling development over time. Lack of this knowledge limits the ability of growers in forest tree nurseries to adjust fertilizer prescriptions to optimize plant growth and minimize potential for seedling damage. It is logical to assume that the variation in nutrient release among PCF products described above would lead to differences in forest seedling development over time. Jacobs and others (2005) compared similar formulations of Osmocote® and Polyon® (each with a 5- to 6-month release period) and found that Douglas-fir seedlings grown with Osmocote® exhibited greater caliper growth and had higher foliar concentrations of N (though lower P) after

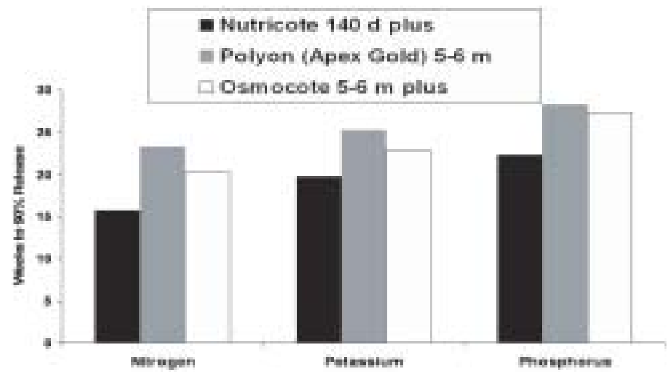

Figure 6—Weeks to 90% fertilizer nutrient recovery from 3 different polymer-coated fertilizer products, each with an approximately 5- to 6-month release timeframe (adapted from Huett and Gogel 2000).

4 months than seedlings grown with Polyon®, although differences were similar at 9 months.

Conclusions

Considerable interest in using PCF in container production of forest tree seedlings has been stimulated by periodic reports of large improvements in initial field growth for seedlings receiving PCF in container media (for example, Nursery Technology Cooperative at Oregon State University, unpublished data). As expectations for reforestation productivity continue to rise, it is likely that interest in using PCF for this purpose will only increase in the future.

It is critical that growers of forest tree seedlings realize that when using PCF, precision of nutrient supply is reduced compared to conventional fertigation. Plant nutrient supply from PCF is largely determined by media temperature, and cool greenhouse temperatures may promote low nutrient release, while sudden increases in temperatures can cause rapid nutrient flushes into media.

Timeframes for nutrient release provided by manufacturers are somewhat crude estimates, and not readily transferable to operation. Release of different individual nutrient elements from PCF varies both in rate and pattern. Patterns of nutrient release also tend to deviate considerably among comparable PCF products.

Variation in nutrient release from PCF should be understood by growers to formulate fertilizer prescriptions that optimize nutrient uptake, minimize leaching, and prevent crop damage. Growers should consistently monitor electrical conductivity levels and supplement with fertigation or leach as needed to ensure optimum nutrient supply.

It is likely that knowledge of crop nutrient requirements over specific developmental stages is as important as knowing the pattern and intensity of nutrient release from PCF. In an attempt to match nutrient supply with seedling demand, prescriptions for incorporating PCF should consider fluctuations in species nutrient requirements when selecting a product. Growers who wish to incorporate PCF into production should carefully monitor seedling development as affected by different products of PCF to identify a fertilizer system that will optimize seedling growth of certain species under a specific nursery cultural regime. New research should be designed to better understand how different products of PCF affect seedling development of important commercial forest tree species, and these results should be effectively transferred to operation.

Acknowledgments

This paper incorporated concepts and presented adapted data from numerous authors and their contributions are greatly appreciated. The Nursery Technology Cooperative (NTC) at Oregon State University has generously supported many research projects designed to improve our knowledge of using PCF in forest seedling nursery production. Patricio Alzugaray, Diane Haase, and Robin Rose contributed many ideas and data from NTC research projects that were incorporated into this paper.

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Seed Production and Establishment of Western Oregon Native Grasses

Dale C. Darris

Dale C. Darris is Conservation Agronomist, Corvallis Plant Materials Center, USDA Natural Resources Conservation Service, 3415 NE Granger Ave, Corvallis, OR 97330; telephone: 541.757.4812 ext 101; e-mail: dale.darris@or.usda.gov

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Abstract: It is well understood that native grasses are ecologically important and provide numerous benefits. However, unfavorable economics, low seed yields for some species, genetic issues, and a lack of experience behind the production and establishment of most western Oregon native grasses remain significant impediments for their expanded use. By necessity, adaptation of standard practices used by the grass seed industry and grassland specialists for introduced species provides the starting point for determining agronomic increase and establishment methods. The USDA Natural Resources Conservation Service, Plant Materials Center at Corvallis, Oregon, has experience increasing at least 15 species of native grasses. It has also conducted studies involving the effects of fertilization, row spacing, post-harvest residue management (burning versus baling), and herbicides on yields of select species. Results are usually species specific, indicating much more research is needed. Fortunately for some native grasses, practical experience has demonstrated the efficacy of certain customary techniques such as carbon banding, timely fertilization, pesticide use, and windrow-combining. Specialty equipment for small grain, seed increase, and processing can be directly transferred or modified for use on native grasses.

Whether for seed increase, revegetation, or restoration, many but not all native grasses possess special challenges. These include dormancy, seed appendages, seed quality, slow growth, and poor competition with weeds. Some are easier to address than others. Other considerations for establishment include equipment, site preparation, and soil amendments such as fertilization. While well documented methodologies readily apply to native grass seeding prescriptions, development of compatible mixtures and appropriate seeding rates requires considerable guesswork. General guidelines and experiences are provided, but substantial work is needed.

Keywords: native grasses, seed production, establishment, seed dormancy, seeding prescription, revegetation, restoration, seeding rates

Introduction

Native grasses are becoming increasingly popular in the Pacific Northwest and elsewhere for revegetation, restoration, erosion control, cover, landscaping, and other uses. However, in western Oregon, availability and wide scale use is limited by a number of factors including economics. With a small market value compared to other crops, there is a lack of research and history behind the seed production of these species. For many native grasses, lack of approved herbicides and established propagation protocols, low seed production, uneven maturity, and genetic issues such as diversity, drift, and isolation increase expense and risk. Restoration use is limited by small markets for individual ecotypes driven by the demand for high site specificity. Given all the unknowns, risks and expenses are considerably higher than for producers of highly bred, introduced pasture and turf grasses.

Furthermore, there are constraints for establishing many important native grasses from seeds. The major challenges are seed dormancy, seed appendages, seed quality, slow germination or initial growth, poor competitiveness with weeds, and a lack of information on seeding methods, such as compatible seed mixtures, fertilization, and seeding rates. Some of these challenges are more easily rectified than others.

Addressing seed production and establishment limitations for select native grasses is part of the role of the USDA Natural Resources Conservation Service, Corvallis Plant Materials Center (PMC). Experience has been gained through experimentation and practical experience. Studies have included the effect of row spacing, nitrogen fertilization, herbicides for annual grass control, and post harvest residue management on seed yield of several species. Over the past 20 years, seed production work has been conducted on 15 native grass species with varying degrees of success. New species are regularly added to the program. The purpose of this paper is to review the Center's seed increase methods for native grasses, provide examples of agronomic trials conducted at the PMC, describe characteristics of native grasses that create special challenges for their use, and provide considerations for site preparation, equipment, seeding methods, mixtures, and seeding rates that apply to revegetation and restoration.

Seed Production

Establishment of New Fields

The starting point for seed increase of native grasses in western Oregon is to evaluate, modify, and incorporate existing technology used by the local seed industry for introduced, cool season pasture and turf grasses. As expected, weed control in new and established stands is usually the premier issue. Herbicides may be effective, but most are labeled only for specific introduced grass seed crops. They cannot be used legally on native species without special licensing for research purposes. Fortunately, one of the most significant chemical weed control practices that can be used when planting native grass fields for increase involves activated charcoal banding (Lee 1973). The method has a label for general grass seed production. As seeds are drilled into the soil, a 1-in (2.5-cm) wide band of carbon slurry is applied directly over each row. Control of germinating annual grasses and other weeds between rows is achieved by broadcasting the herbicide diruon immediately afterwards. The carbon absorbs the chemical and prevents it from killing the crop seeds. Another herbicide used in this situation is pronamide, but it is only labeled for introduced perennial ryegrass (*Lolium perenne*), tall fescue (*Festuca arundinacea*), and orchardgrass (*Dactylis glomerata*) (Colquhoun 2003). Certain phenoxy herbicides may be applied at the 3-leaf stage of the grass crop or beyond for broadleaf weed control. Other herbicides are listed for specialized control (Colquhoun 2003).

Late summer and early fall is the preferred time to establish new production fields of most native grasses in western Oregon. Planting at this time has several advantages over spring seeding. Known and unknown seed dormancies can be overcome by exposing the seeds to cool, moist soil conditions over winter; the need for spring irrigation may be eliminated, and a good seed crop may be possible the first full growing season for rapid developing species. In general, the Corvallis PMC does not fertilize with nitrogen at the time of planting because it contributes to excessive weed competition. Exceptions may be made if the soils are known to be low in weed seed content. Usually, commercially available carbon slurry will already contain a low rate of starter fertilizer. There is little value to fertilizing at planting time if the seeds are dormant for 60 days or longer.

Presently, most grasses grown at the Corvallis PMC are bunch grasses and suited to row culture. Production in well defined rows simplifies weed control and contributes to satisfying seed certification requirements. Row spacing and seeding rates vary by species and are interdependent. Most species with medium to large seed sizes are initially grown in 12-in (30.5-cm) rows and seeded at a rate of 10 to 15 PLS (pure live seed) lb/ac (11 to 17 PLS kg/ha). Because of equipment, row spacing is widened to 28 in (71 cm) when new fields are started from container stock using a 2-row transplanter. In order to refine these practices, trials and other work have been conducted on select species by the PMC. Flessner (2000a) found that for American sloughgrass (*Beckmannia syzigachne*), a seeding rate of 12 PLS lb/ac (13 PLS kg/ha) and a row spacing of 6 in (15 cm) optimized seed yield, suppressed weeds, and enhanced stand vigor. Experience has shown that species like blue wildrye (*Elymus glaucus*) and California brome (*Bromus carinatus*), with large seeds and vigorous seedlings, are well suited to 8 to 10 lb/ac (9 to 11 kg/ha) (20 to 35 live seeds/linear ft [66 to 117 seeds/linear meter]) seeding rates in 12-in (30.5-cm) rows. Rates can be adjusted lower for wider rows (Darris and others 1996). In contrast, tufted hairgrass (*Deschampsia caespitosa*) has small seeds (1.8 million/lb [4 million/kg]), and therefore a seeding rate of 1 to 2 PLS lb/ac (1 to 2 kg/ha) is acceptable (Darris and others 1995). An experiment comparing the effect of row spacing on seed yield demonstrated that the best production for this species occurs with 24- to 36-in (61- to 91-cm) wide rows under high soil fertility but no irrigation (Darris and Stannard 1997) (Figure 1).

Management and Harvest of Existing Stands

Pest Management—Pest management in established stands of native grasses at the PMC focuses on weed and disease control. Broadleaf weeds are controlled once or twice a year with phenoxy herbicides. Other fall or early winter application of herbicides like diuron, Prowl® (pendimethalin), or Axiom® (flufenacet+metribuzin) may be made for experimental control of annual bluegrass (*Poa annua*) and rattail fescue (*Vulpia myuros*) (Colquhoun 2003). However, these annual grass control chemicals are not labeled for native grasses and their use is limited to research. Figures 2 through 4 show the effects of 6 herbicide treatments on the control of annual grasses and seed production in meadow barley, California oatgrass (*Danthonia californica*), and tufted hairgrass respectively. The study was conducted at the PMC in 2001 to 2002. Results varied by species. Chemical names are used for information purposes only and are not an endorsement of the product. Other weed control measures include spot treatments with glyphosate, mowing of weeds that overtop the grass (primarily in year 1), and manual methods. Mechanical cultivation is rarely used. Shielded row spraying with glyphosate holds promise and needs evaluation. In terms of fungal pests, stem or leaf rusts (*Puccinia* spp.) appear most detrimental to Roemers fescue (*Festuca roemeri*), meadow barley (*Hordeum brachyantherum*), and pine bluegrass (*Poa scabrella*) grown at the PMC. The fungicides Bravo® (chlorothalonil) and Tilt® (propiconazole) are used in spring for their control (Pscheidt and Ocamb 2003). Fungal smuts (*Tilletia* spp. or *Ustilago* spp.) are a particular problem on California brome. Under some circumstances, the diseases may be legally controlled by treating the seeds with Vitavax® or other fungicide combinations (Pscheidt and Ocamb 2003). Other pests, such as insects, voles, nematodes, and slugs, may play a role in

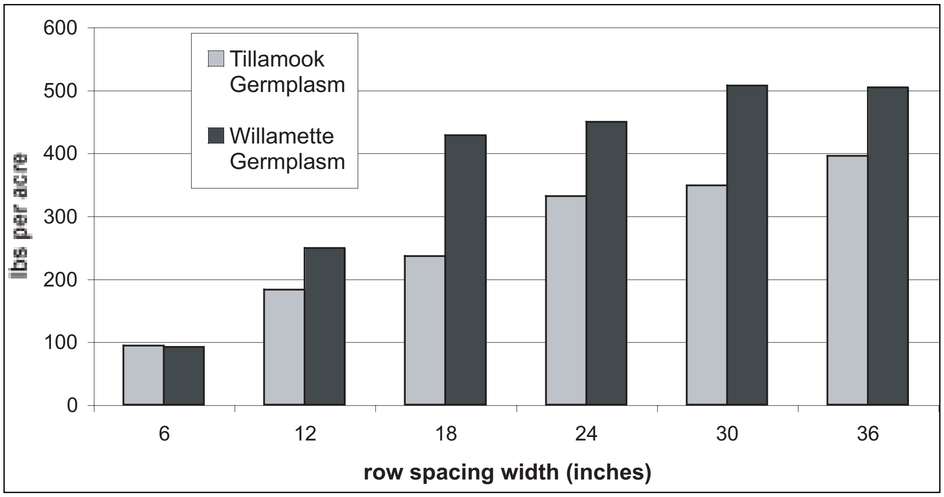

Figure 1—Effect of row spacing on seed yield of tufted hairgrass (1993 to 1995).

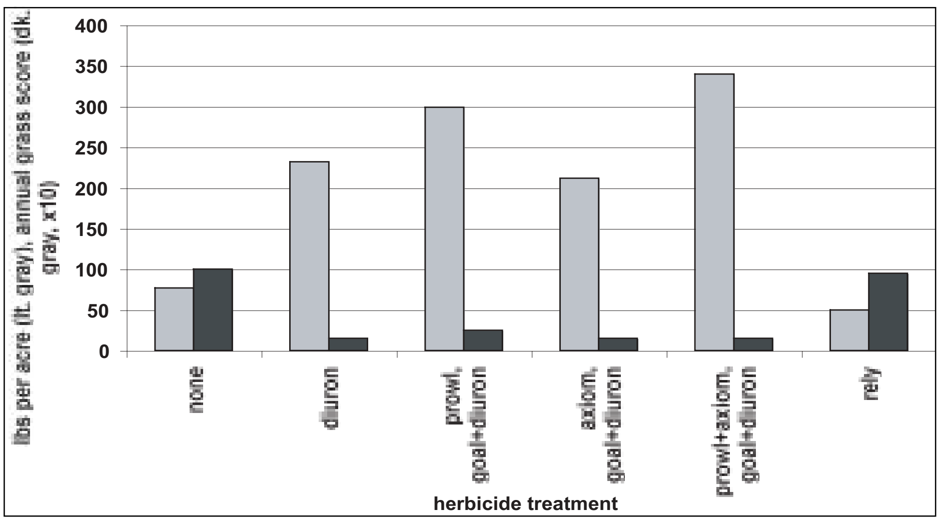

Figure 2—Herbicide effect on seed yield and annual grass control in meadow barley.

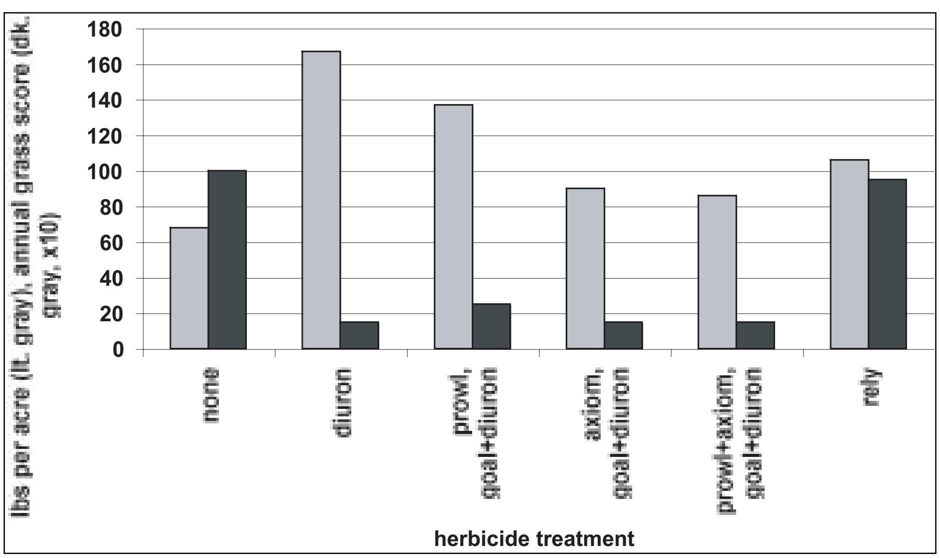

Figure 3—Herbicide effect on seed yield and annual grass control in California oatgrass.

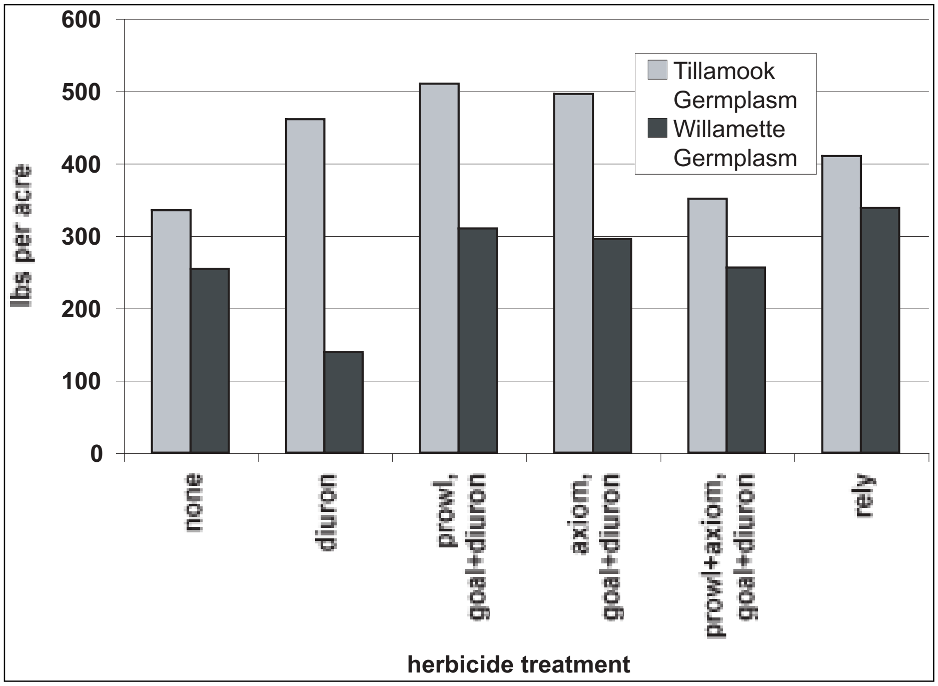

Figure 4—Herbicide effect on seed yield of tufted hairgrass.

native grass seed production as they do with introduced grasses in the Willamette Valley of Oregon (Lies 2002).

Irrigation—Irrigation is primarily used for establishment, although regular, summer irrigation has been successfully used to produce seeds of tall mannagrass (*Glyceria elata*), a wetland species being grown on a moderately well drained silt loam. The influence of fall irrigation on seed yield of some species needs to be investigated. Other wetland grasses, such as American sloughgrass, rice cutgrass (*Leersia oryzoides*), and bluejoint (*Calamagrostis canadensis*), are produced in ponds at the PMC using permanent shallow or intermittent inundation. Irrigated fields, seasonally wet depressions, and lowlands with poorly drained soils may also be suitable.

Fertilization—Optimal fertilization rates for most native grasses are unknown, although an experiment with tufted hairgrass (Figure 5) illustrated the importance of a 50 to 100 lb/ac (56 to 112 kg/ha) nitrogen application in late winter or early spring (February to March). Surprisingly, fall fertilization was not a significant benefit as it is with other species. Until more is known about individual species, fertilization of established, cool season grasses at the PMC generally consists of 25 lb/ac (28 kg/ha) of nitrogen in the fall and a single or split application of nitrogen at 50 or

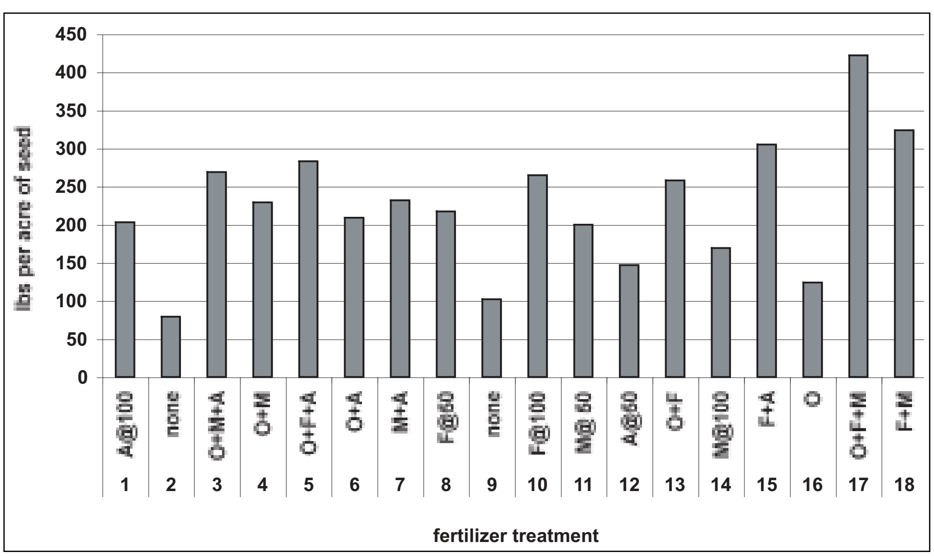

Figure 5—Effect of N fertilization on seed yields of tufted hairgrass (4 reps, 3 years). (For fertilizer treatments, O = October at 25 lb N/ac [28 kg N/ha] and F = February, M = March, and A = April at 50 lb N/ac [56 kg N/ha]. Exceptions are treatments 1, 10, and 14 where N was applied once at 100 lb/ac [112 kg/ha].)

75 lb/ac (56 or 84 kg/ha) in early spring. The total is 75 to 100 lb/ac (84 to 112 kg/ha) per year. Rates may be lowered to 25 lb/ac (28 kg/ha) for species that produce less herbage. In addition, an application of 10 to 15 lb sulfur/ac (11 to 17 kg sulfur/ha) per year is typical. Although soil pH, potassium, and phosphorous have rarely been limiting at the PMC, it is suggested that lime and other nutrients be applied according to soil ppm standards established for introduced fine fescue (Gingrich and others 2003) and tall fescue (Doerge and others 1983) when managing similar sized native grasses. Grass seeds produced in ponds are fertilized with low rates of slow release fertilizer or not at all to avoid algae bloom.

Harvest—Harvest of native grass seeds may follow standard procedures or incorporate specialized equipment and techniques. Estimated seed yield potentials are shown in Table 1. At the PMC, fields 0.25 ac (0.10 ha) or larger are first swathed (windrowed) when most seeds are in mid to hard dough stage of ripeness; this may occur earlier for certain species. The timing depends on the species resistance to shattering and the variation in maturity within each field. Windrowing allows for stems to dry and greener seeds to catch up and mature. If conditions have remained dry, harvesting is done with a mini-combine usually within 3 weeks after windrowing. Other methods used at the Center include manual harvesting with rice knives, hand clippers, and scythes, and direct harvesting with a hand-held seed stripper or flail-vac seed stripper. The flail-vac seed stripper is mounted on the front of a tractor like a front end loader. Its large spinning brush strips and vacuums seeds off the heads. Small areas may also be mowed with a sicklebar mower. The stalks are then gathered and dried on a tarp or warehouse floor prior to being run through a plot thresher to separate seeds from stems and chaff. Hand harvest and mechanical stripping methods are practical for a species like meadow barley, which matures downward from the terminus of the seed head, or for those fields with high genetic diversity, indeterminate flowering, and uneven maturation. Unfortunately, a substantial quantity of seeds is lost with mechanical strippers. A solution is to lay plastic between the rows and sweep or vacuum the seeds up after they drop onto the sheets. In other cases, light chaffy seeds may be vacuumed directly from seed heads (Burton and Burton 2004b). For species that lose excessive amounts of seeds in the windrow as they dry, strips of paper can be laid down in the field. The windrows or stalks are forked onto the sheets or they can be swathed directly onto the paper by a windrower equipped to handle paper rolls.

Finally, post harvest residue management is practiced on native grasses as it is with introduced grasses in western Oregon. Residue removal or related post harvest treatments are widely known to improve seed yields of most grass seed crops. With the gradual phase-out of field burning in Oregon, significant University and USDA research has gone into developing alternative methods of handling residue. There are more than a dozen common practices for introduced grasses in Oregon, from thermal to clean non-thermal and full straw load methods (Lies 2002). Many of these techniques are species specific and, unfortunately, few investigations have been conducted on native grasses in the area. The PMC found that for blue wildrye, there was no significant difference in seed yield between baling, baling and burning, baling and mowing, and baling, mowing, and burning with a propane field flamer (Darris and others 1996). In a demonstration with tufted hairgrass, burning did not improve yields over baling and mowing of residues. Until more investigations are conducted, standard practice for all field grown native grasses at the Center is to bale crop aftermath then flail mow the remaining stubble.

Special Challenges and Solutions

Seed Dormancy

Certain characteristics of native grass seeds can pose challenges or complications for seed production as well as for use in revegetation and restoration. As alluded to earlier, a number of these species possess seed dormancies that influence establishment procedures. While there are many types of seed dormancy, it appears that the most common types found in native grasses can be overcome, at least in part, by cold, moist stratification. This method is the same as moist pre-chilling, or placement of seeds into a cool environment on, or in, a moist medium. Table 1 shows results of seed germination work done at Center. Results may not necessarily agree with those published elsewhere. Dormancy within a species may vary between populations, by age of the seed lot, or by crop year. Precision planting may require both a seed germination and TZ (tetrazolium) viability test to ascertain the amount of dormancy. In general, stratified and imbibed seeds can be spring sown with certain equipment, but the simplest solution for handling dormancy is to fall plant untreated, dry seeds.

While seed dormancy impacts the establishment of seed production fields, it complicates the formulation of compatible seed mixtures and seeding rates for revegetation and restoration prescriptions. Therefore, it is often best to sow dormant seeds alone. However, if temporary cover is required for erosion control, a simple grass seed mixture may be the only option. In this situation, it is suggested that only a small portion (10 to 20% of the mix) of a less competitive, short-lived grass be used with a large amount of the grass with dormant seeds. Otherwise, too much of one grass, especially a fast germinating or competitive one, may fully occupy the site and preclude establishment of target species. Two potential choices are native slender hairgrass (*Deschampsia elongata*) and annual hairgrass (*Deschampsia danthoniodies*). They are short-lived and appear to be less competitive. Seeding alone also provides the opportunity to use an herbicide or fire to kill weeds that emerge after planting but prior to emergence of the grass seedlings. Breeding or selection for non-dormant seeds is not considered an option for restoration work where preservation of genetic diversity and integrity within species is a top priority.

Seed Conditioning and Cleaning

Some native grasses have seed appendages and hulls that may need to be removed by physical conditioning to improve flow through seeding equipment, improve germination, or

Table 1—Seed production and seed characteristics of major western Oregon native grasses.

Common name	Scientific name	Habitat[a]	Seed yield[b]	Seeds/lb[c] w/hulls (w/o hulls)	Seed stratification[d] (cold/moist)	Seeds/ft² 1 lb/ac	Remarks
Pine (rough) bluegrass	*Poa scabrella* (*P. secunda*)	DU, MU	Low	1,520,000	14-60 days	35	Florets may need separating
Roemer's fescue	*Festuca roemeri*	DU, MU	Low	502,000	14 days (optional)	12	Poor seed fill may occur, prone to rust
California oatgrass	*Danthonia californica*	DU, MU, WP	Low	95,000 (220,000)	70-90 days	2.2 (5)	Slow development, scarifiing may incr. germ.
Prairie junegrass	*Koeleria macrantha*	DU, MU	Low	1,250,000	None	29	Poor seed fill may occur
California brome	*Bromus carinatus*	DU, MU	High	82,000	None	1.9	Easy to produce, weedy, prone to smut
California fescue	*Festuca californica*	DU, DF, MU	Low	130,000	None	3	Slow seedling development
Slender wheatgrass	*Elymus trachycaulus*	DU, MU	High	110,000	None	2.5	Easy to produce, vigorous seedlings
Lemmon's needlegrass	*Achnatherum lemmonii*	DU	Low	92,000	60-90 days	2.1	Hard to produce, remove awns
Western needlegrass	*Stipa occidentalis*	DU, MU	Low	274,000	90 days	6.3	Hard to produce, remove awns
Hall's bentgrass	*Agrostis halli*	DU, DF, MU	Low	5,000,000	None	115	Slow seedling development, has rhizomes
Harford's melic	*Melica harfordii*	DF, MF, MU	Low	140,000 (195,000)	70-90 days	3.2 (4.5)	Can be hulled, has short rhizomes "bulbs"
Slender hairgrass	*Deschampsia elongata*	MU, MF, WP	Medium	2,400,000	None	54	Easy to produce, delint seed, can be hulled
Blue wildrye	*Elymus glaucus*	MU, DF, MF	High	140,000	None	3.2	Remove awns, vigorous, easy to produce
Sitka brome	*Bromus sitchensis*	DF, MF, MU	High	83,000	None	1.9	Easy to produce, weedy, vigorous
Columbia brome	*Bromus vulgaris*	MF	Medium	92,000	None	2.1	Needs partial shade, can be hulled
Bearded fescue	*Festuca subulata*	MF	Low	267,000	30 days	6.1	Needs partial shade, remove awns
Western fescue	*Festuca occidentalis*	DF, MF	Low	600,000	None	14	Hard to produce, needs partial shade
Alaska oniongrass	*Melica subulata*	DF, MF	Low	? (180,000)	70-90 days	4.1	Can be hulled, has short rhizomes "bulbs"
Nodding trisetum	*Trisetum cernuum*	MF	Low	1,000,000	None	23	Remove awns
Spike bentgrass	*Agrostis exarata*	MU, WP	Low	5,400,000	None	124	Easy to produce, volunteers readliy
Tufted hairgrass	*Deschampsia caespitosa*	MU, WP	Medium	1,400,000 (1,800,000)	none	32 (41)	Needs wide rows, delint seed, can be hulled
Meadow barley	*Hordeum brachyantherum*	MU, WP	Medium	150,000	None	3..4	Remove awns, multiple harvests needed
Annual hairgrass	*Deschampsia danthonioides*	WP	Medium	900,000	None	21	Can be hulled, delint seed, poor competitor
Western sloughgrass	*Beckmannia syzigachne*	M, WP	Medium	238,000	None	5.5	Irrigate, hull removal improves germ.
Tall mannagrass	*Glyceria elata* (*G. striata*)	MF	Medium	1,600,000	14-60 days (optional)	37	Irrigate, slow or uneven germination
Western mannagrass	*Glyceria occidentalis*	M	Low	? (360,000)	None	8.3	Irrigate, shatters when green, seed in stem
Slimheaded mannagrass	*Glyceria leptostachya*	M	Low	1,300,000	None	30	Irrigate, may need multiple harvests
Rice cutgrass	*Leersia oryzoides*	M	Medium	361,000	180-240 days	8.3	Not suited to rows (rhizomatous), irrigate
False mannagrass	*Torreyochloa pallida* var. *pauciflora*	WP, M	Medium	1,955,000	None	45	Rhizomatous, irrigate
Bluejoint	*Calamagrostis canadensis*	MF, M, B	Low	4,050,000	None	93	Rhizomatous, may have poor seed fill, irrigate
Nodding semaphoregrass	*Pleuropogon refractus*	MF, B	Low?	59,000	60-90 days	1.4	Irrigate, slow establishment

[a] For generalized habitat, DU = dry upland (sun), MU = moist (mesic) upland, DF = dry forest, MF = moist forest, WP = wet prairie, M = marsh, B = bog.
[b] Estimate only. Yields vary substantially due to genetics, pollination, management, age, and so on, and can be higher or lower than estimate. Low = 50 to 250 lb/ac (55 to 280 kg/ha), Medium = 250-450 lb/ac (280 to 500 kg/ha), High = 450-700 lb/ac (500 to 785 kg/ha).
[c] Seeds per pound are estimates only. Results will vary as much as 30%, depending on seed lot, year, genetics, and other factors. Amount of seed conditioning such as de-awning, de-hulling, de-linting, and so on can also significantly effect seed weight per pound.
[d] Seed stratification requirements (and thus dormancy) may differ between and within populations, by age of seed, or by seed lot. Other seed treatment methods besides stratification and fall sowing/overwintering may eliminate or reduce dormancy in certain species.

reduce bulk. Conditioning also facilitates seed cleaning, resulting in higher quality seeds. Examples of troublesome appendages are the long awns on blue wildrye and the pubescence found on hairgrass and bluejoint seeds. In either case, failure to remove them can hamper the effective use of common seed drills and cyclone seeders. Seed hulls are the "seed leaves" (lemma and palea) that surround the true seeds (caryopsis). They may or may not be tightly fused to the hard outer seed coat (pericarp). Normally, hulls don't cause a problem unless some of the seeds readily separate from the hulls. In this case, all the seeds should be mechanically hulled to create a uniform seed size and prevent the waste of good seeds during cleaning. The PMC accomplishes both appendage and hull removal with a huller/scarifier or "brush machine." It operates by means of brushes that spin inside a drum shaped cage. The brushes rub seeds against the walls of the drum to condition it. Other types of machines can work as well, including debearders and hullers. Hulling or rubbing, which in turn scarifies the pericarp, may also improve germination in certain species (Trask 1996; Flessner 2000b).

Obtaining only the purest, high quality seeds, even beyond the standards set by law and seed certification, should be the goal of any native grass seed producer. One of the underlying reasons for using natives is to avoid and counteract the spread of exotic weeds. Therefore, there should be "zero tolerance" for noxious and other troublesome weed seeds in any seed lot (Burton and Burton 2004a). Seed cleaning to remove weed seeds, as well as empty seeds, stems, and trash, is primarily accomplished with an air screen machine (fanning mill). It separates seeds by size and weight. Other specialty equipment used by the Center includes an indent cylinder which separates by seed length, a vibrating table which separates by seed surface texture and shape, and an air density separator that distinguishes by seed weight and ballistics. Meeting the challenge of exceptional purity often means natives must be re-cleaned more frequently and meticulously than the typical introduced grass seed crop.

Seed Lot Size and Equipment

With both native grass seed production and revegetation, practitioners regularly deal with small quantities of seeds, often just a few pounds or even grams. There are relatively few economical options for working at this scale, requiring either extensive hand labor or an investment in expensive garden, lab size, or specialized harvest, seed processing, and planting equipment. For some applications, commercial devices are unavailable and equipment may need to be fabricated. In other cases, equipment meant for grain production must be modified to handle grass seeds, which are much lighter and finer. One of best ways to stretch scarce seeds and improve volume for use in larger equipment is to dilute seeds with rice hulls. When planting mixtures, rice hulls suspend seeds in the hopper and help prevent different sizes from separating out and being sown unevenly. For manual seeding with smaller or darker seeds, rice hulls allow for better visual inspection of broadcast uniformity. Other inert carriers include cracked or roasted grains, cat litter, and vermiculite. An inexpensive alternative to hand seeding and costly equipment is the old fashioned cyclone spreader or "belly grinder." Single row manual seed drills such as the planet junior are still commercially available. For cleaning small quantities of seeds at low cost, hand-held screens and sifters are useful. Manual rubbing boards or troughs may be used to remove awns and pubescence.

Yield, Maturation, and Genetic Integrity

Low seed yields, non-uniform maturity, and maintenance of genetic integrity are inherent challenges when producing many native grasses. Breeding or intensive selection are typically not an option for natives used in restoration, so naturally low yields can only be maximized by refining agronomic techniques. While non-uniform maturity is often the result of desirable genetic variability within a population, it poses additional problems. Failure to capture seeds that mature at different times not only means a loss in production, but also a reduction in diversity through genetic shift. The method of windrowing then combining is better than direct combining for harvesting seeds of uneven maturity. However, when maturity differences and shattering losses are extreme, multiple harvests of the same field are the best but costliest solution. For small plots, the PMC resorts to hand harvesting smaller fields on different dates. For larger stands, several passes with a flail-vac stripper have been used with some success on meadow barley and California oatgrass. Another option is to grow several subsets of the same population with different maturities in adjacent fields or rows.

Besides unintentional selection by harvesting species with uneven maturation, genetic modifications could occur for other reasons. To address this, variety and pre-variety seed certification guidelines are applied by the PMC whenever possible (Oregon State University Extension Service 2004). The Center minimizes genetic changes over time by restricting the number of successive generations or stands to 2—G1 and G2—with G0 being wild seed. If seed lots leave the PMC for commercial increase, production may be limited to G2 or G3. The number of years a field is in production may be kept short as well. The Oregon Seed Certification Service now has tentative pre-variety germplasm (G1, G2, and so on) standards for 14 native grasses (Schrumpf 2003). Lastly, to minimize unwanted cross pollination between ecotypes of the same species, the PMC uses a target isolation distance of at least 1,000 to 1,200 ft (300 to 365 m) for both open and self-pollinated species, regardless of field size.

Germination, Growth, and Competition

Slow germination, slow growth, and a lack of competitiveness with weeds are frequently interrelated and may be the most limiting factors for establishing many native grasses from seeds. To compensate, sowing a species alone at higher rates is one possible solution. However, seeds are expensive, and seeding rates have upper limits because of intraspecific competition. In order to ensure success, one of the best strategies is to reduce the weed seed content in the soil through site preparation methods that include 1 to 2 years of fallowing prior to planting. Ideally, several cycles of tillage and glyphosate applications are utilized to encourage and then destroy germinating weed seedlings at critical times of the year. However, this technique may not be possible on steep banks or in certain non-agricultural settings. It may be unnecessary on recently farmed fields where the weed seed levels are already low. If the native grass seedlings are slow to germinate and emerge, weeds that appear in the interim after planting can be killed by herbicides or burning, as described for dormant seeds. Like the establishment of seed increase fields, timely mowing of weeds that overtop the native grass and the use of selective herbicides may be options for revegetation plantings as well.

Further Considerations for Revegetation and Restoration

When it comes to seeding prescriptions for revegetation and restoration using native grasses, there is no "cookie cutter" approach because almost every site is in someway unique. Furthermore, with the exception of a couple species, long term experience using native grasses in western Oregon and western Washington is lacking. Therefore, technology is often extrapolated from work on introduced grasses in the region or from native species in other parts of North America with a longer history of use. Suggested methods and factors to consider when using native grasses are based on work by others and experience gained by the PMC.

Site Preparation and Weeds

As discussed, site preparation and early weed competition are critical considerations for success. One suggestion is to sample the top layer of soil from the site and conduct "grow outs" to estimate weed seed load and species composition. The soil should be placed in shallow trays in a greenhouse or similar environment, watered for 4 weeks, the seedlings harvested, and the soil allowed to dry. It is re-watered to permit seeds to germinate several times (Waters and others 2001). Because different species will germinate in the spring versus fall, seedling counts could be recorded at both times. Additional counts should be taken after overwintering the soil sample outdoors in a moist condition. Another method is to create open test plots for 2 to 3 years in advance on the site and observe what species volunteer. In a few cases, there may be a valuable seed bank of native species. Knowledge of potential weeds will aid in the choice of a site preparation technique. Attempts to preserve existing, desirable species on site will substantially affect methods as well (Campbell 2004). Techniques usually include some combination of burning, mowing, deep ripping, disking, harrowing, herbicides, soil solarization, fertilization, and incorporation of organic amendments. Soil fallowing and formation of a firm, weed-free seedbed for shallow seed placement are still the best methods for proper seed-soil contact, but they are not suitable for all situations.

Fertilization

The decision to use fertilizer or not is site specific and not without controversy. Most restoration projects in the region leave fertilizer out of the prescription because it exacerbates weed competition. There are also water quality issues with high rates of soluble fertilizers, especially near waterways. However, some seeding guides recommend fertilizer for quicker establishment and higher canopy cover. The PMC avoids fertilizing new plantings where topsoil is well developed, water quality is a concern, or weeds are a major factor. The Natural Resources Conservation Service only recommends fertilizing when subsoil is exposed and a soil test is done. It does not recommend fertilizing diverse mixes of forbs, legumes, and grasses, or seedings on rangeland, wetland, Conservation Reserve land, permanent pastures, and riparian sites (USDA-NRCS 2000). In special situations, slow release fertilizers may be an option, but they are expensive. Some States have specific guidelines for their use (Minnesota Department of Transportation 2003). Seed coating or prilling may be another possibility. Nitrogen, phosphorous, lime, or other nutrients are attached to the seeds of introduced pasture grasses. The method also improves ballistics for aerial seeding and reduces wildlife seed predation; testing is needed with native grass seeds. Nitrogen can be added naturally to a soil by including a native legume in the seed mixture. The fact that nitrogen may favor weed growth over natives is often problematic. In the last 10 years, several researchers have been evaluating "reverse fertilization." It involves application of sawdust or other high carbon material to the soil in an attempt to reduce nitrogen levels available for exotic weeds, thereby favoring the growth of native species. Results have been mixed (Averett and others 2002; Blumenthal and others 2003; Corban and D'Antonio 2004).

Seeding Methods

The choice of seeding method depends on site conditions, site preparation, seed characteristics, equipment availability, labor, economics, and other factors. A standard grain drill may be used following conventional tillage. No-till drills minimize site disturbance and may reduce weed invasion. However, drill rows can leave an unnatural appearance for restoration. Therefore, broadcast seeders equipped with fluted feeders and cultipackers or cyclone seeders may be more desirable. To ensure flow, standard equipment requires that certain grass seeds be conditioned first or carriers added with the seeds. If seed appendages, chaff, or pubescence have not been removed during seed processing, or the seeds are very light, special native grass drills are available. They have picker wheels in the seed box and large drop tubes that prevent the seeds from bridging and plugging up. Depth bands on the furrow openers ensure shallow seeding depth. In addition, hydroseeding is an option for steep, inaccessible sites. Finally, mulches or erosion control blankets applied at seeding time are almost always a good idea, especially on erosive, steep, and dry sites. Common materials and methods readily apply to native grasses.

Seed Mixtures and Monocultures

Prescribing a seed mixture requires knowledge of species compatibility as well as seed and seedling characteristics. As described earlier, species with dormant seeds may best be seeded alone or only with a short-lived, weak competitor. For quick cover and erosion control, consider seeding large, fast establishing native grasses like California brome, blue wildrye, and slender wheatgrass (*Elymus trachycaulus*) alone or in their own mix. If they are included with slower, smaller species, it is generally recommended their rates be kept low and not exceed 5 to 10% of the total PLS seeding rate in order to avoid dominating the stand. Seeding mixtures with 5, 10, and even 25 different species can be found in the literature for other regions of North America. However, given the limited experience and high cost of native herbaceous seeds in western Oregon, one suggestion is to keep mixes simple by including no more than 2 to 4 native grasses. Seeding trials by the PMC have resulted in the complete exclusion of certain grasses in a mix. In addition, many forbs are not competitive with grasses and may need to be planted later or separately. Exceptions include adding a native legume for nitrogen fixation or another forb that is a competitive pioneer. If forbs are included in the mix, early weed management options are reduced, including the use of broadleaf herbicides. Mixes should also be site specific. Those designed for diversity and ecological restoration should follow the concepts of mosaic seeding (Campbell 2004) and sculptured seeding (Jacboson and others 1994) to mimic natural patterns in the environment.

Monocultures are appropriate for temporary, fast cover such as on construction sites and landslides, or they could be used in progressive stages. A site could be restored by first establishing a less expensive, native cover crop that competes well with residual weeds. Other situations could begin with a long-lived species that will serve as the dominant matrix of the plant community. By the third year, slower growing and more expensive grasses are interseeded, alone or as mixes, into the existing stand or newly created bare areas. Finally, by the third or fourth year, forbs are likewise interseeded, planted as container stock, or sown in patches. This staging process allows for simplified “plot management” and retains optional use of selective herbicides. It may also improve the chances of success with expensive, slow, and difficult to establish species, but may significantly add to other costs. The process needs more testing.

Seeding Rates

Given the lack of history behind the use of native grasses in the region, seeding rate development involves substantial guesswork and the search for comparable experiences. Rates will depend on factors including objectives, growth rate, seed and seedling traits, site conditions, and method of planting. They may vary from as low as 0.5 lb/ac (0.6 kg.ha) for species with tiny seeds, to over 250 lb/ac (280 kg/ha) for turf plantings. For revegetation and restoration, the general range is 1 to 20 (5 to 15) lb/ac (1 to 22 [6 to 17] kg/ha) where weed competition is minor and seedbed preparation nearly ideal. The total amount per acre is the same for single species and mixes. Higher rates in the scope of 25 to 60 lb/ac (28 to 67 kg/ha) may be needed for erosion control on steep banks or weed suppression. Critical areas and broadcast seeding methods often specify doubling the drilled amount. Rates should be calculated on a PLS lb/ac and not a bulk lb/ac basis. Furthermore, the most accurate method of rate determination uses pure live seeds/ft^2. For many PMC projects, an initial target rate of 50 live seeds/ft^2 (555 live seeds/m^2) is common. It is then adjusted up or downward depending on species, site conditions, and objectives. In practice, the recommended range may vary from 18 to 90 seeds/ft^2 (200 to 1,000 live seeds/m^2) (USDA-NRCS 2000). Under extreme conditions, this quantity could be higher because estimates are that 90% or more of the seeds are readily lost for various reasons, including dehydration, predation, erosion, and improper planting depth. For certain situations, the PMC has found it useful to sow at densities up to 300 seeds/ft^2 (3,330 live seeds/m^2). Amounts above this are probably a waste of good seeds. Table 1 contains information on seeds/lb and the number of seeds/ft^2 at a 1 lb/ac (1.1 kg/ha) seeding rate.

Present and Future Work

The Corvallis Plant Materials Center has been evaluating and producing seeds of native grasses for more than 2 decades. While the principle species have been blue wildrye, tufted hairgrass, California brome, and California oatgrass, at least 10 new species have been added since 1996. Seeds are produced for research use, special agency field plantings, commercial growers, and cooperative agreements. Presently the PMC has several increase projects targeted for land restoration by the National Park Service and Bureau of Land Management. Evaluations will continue on refining seed production and revegetation techniques with native species.

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Cultural Plant Propagation Center: Things to Consider

John W. Bartok, Jr.

John W. Bartok, Jr., is Extension Professor Emeritus and Agricultural Engineer, Natural Resources Management and Engineering Department, University of Connecticut, Storrs, CT 06269-4087; telephone: 203.486.2840; e-mail:jbartok@rcn.com

In: Dumroese, R. K.; Riley, L. E.; Landis, T. D., tech. coords. 2005. National proceedings: Forest and Conservation Nursery Associations—2004; 2004 July 12–15; Charleston, NC; and 2004 July 26–29; Medford, OR. Proc. RMRS-P-35. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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Keywords: greenhouse culture, environmental controls, greenhouse design

Is a Greenhouse Necessary?

There are many career opportunities in horticulture, plant science, and other agricultural disciplines. Horticulture is one of the fastest growing segments of agriculture. Students that gain experience in greenhouse techniques have an advantage when applying for a job.

Integrate the Greenhouse With Program Activities

Who will use the facilities? This use could include classes in botany, plant science, agri-science, environment, evening programs for farmers and gardeners, and production of plants for landscaping school grounds.

What Is Typically Taught in Greenhouse Classes?

Typical classes can include seed germination, plant propagation, planting and watering techniques, plant identification, greenhouse management, growing media selection, temperature control, and effect of water quality on plant growth.

Integrate the Greenhouse With the School Building

The best location is an east-west orientation on the south side of the school. An attached greenhouse allows access to the school without going out into the weather. It may also provide convenient work space and storage.

A free-standing greenhouse usually gives more flexibility in orientation and size, and allows space for gardens or a shadehouse and room for expansion. However, utilities are usually more difficult to provide.

Design for Flexibility

Programs, the type of plants grown, and the number of students using the greenhouse change from year to year. Benches should be portable. The heating and cooling system should be out of the way. For a school greenhouse, a paved floor allows access to all parts of the greenhouse and accommodates students with disabilities. For a production greenhouse, a central paved aisle with weed barrier and stone under the benches is less expensive and allows drainage. Design for different environments for different crops.

Who Will Manage the Greenhouse?

Plants need attention several times a day, 7 days a week. This means that someone will have to come in on weekends and holidays. One person should be given the responsibility for overseeing the operation, making decisions on space allocation and environmental requirements. A parent committee, greenhouse club, or garden club can be formed to assist in watering the plants and doing other chores.

How Large Should the Greenhouse Be?

The size of the greenhouse will depend on the number of students and the amount of class time spent in the greenhouse. Generally, a 24 by 48 ft (7 by 14 m) greenhouse will provide work area and bench space for 20 to 25 students. Storage space for growing media, containers, and equipment can be provided with a utility shed.

Create Additional Growing Space

A shadehouse, high tunnel, or cold frames can be added to create low cost growing space to supplement the greenhouse. When planning the greenhouse, leave space for expansion, auxiliary structures, and outdoor growing beds.

What Is the Cost of Building a Greenhouse?

Costs vary with the style of greenhouse, the glazing materials, type of foundation, amount of environment control, site preparation required, connections to utilities, and who does the construction. A film plastic covered hoophouse may cost as little as U.S. $\$15/ft^2$ (U.S. $\$167/m^2$), whereas a steel-frame greenhouse covered with tempered glass and having electronic controls may run as high as U.S. $\$50/ft^2$ (U.S. $\$555/m^2$). Using local labor may lower the cost somewhat.

What Are the Operating Costs?

The main cost is for heat, and it varies with the greenhouse size, glazing, and climate. Assuming a 24 by 48 ft (7 by 14 m) double glazed greenhouse, 60 °F (16 °C) night temperature, and fuel costs (propane at U.S. $2.00/gal [U.S. $0.50/l]; natural gas at U.S. $1.15/therm; and fuel oil at U.S. $1.50/gal [U.S. $0.40/l]), winter heating costs will be approximately: (1) natural gas and fuel oil at U.S. $3,000 in the northern tier and U.S. $2,000 in the mid-tier of States; (2) propane at U.S. $5,000 in the northern tier and U.S. $3,500 in the mid-tier of States.

Costs in addition to heat include: (1) approximately U.S. $400 for equipment maintenance; (2) from U.S. $200 to U.S. $300/year for electricity, excluding any supplemental plant lighting; and (3) approximately U.S. $600 for growing supplies (mix, containers, seeds, fertilizer, and so on).

For school greenhouses, some funds can be raised by selling plants. Other sources might be raffles, scratch tickets, book subscription sales, and so on.

What Are Typical Glazing Materials?

For school greenhouses, the standard material is structured sheet polycarbonate, as it is strong, lightweight, flame retardant, and has good insulation and light transmission. For production greenhouses, double layer, 6-mil, greenhouse grade polyethylene film, if inflated, will provide 4 years of service before it has to be replaced. Always use clear material to get maximum light transmission.

Keep Environment Control System Simple

Good temperature control is necessary for good plant growth. Hot air systems are the least expensive and can be mounted above or below the benches. Boiler systems, though more expensive, are a better choice for larger greenhouses if more uniform temperatures and root zone heating are desired.

Fan cooling systems give the best summer control of temperature. They can be operated in stages, with the final stage being evaporative cooling. Natural ventilation systems (vents or roll-up sides) work well when someone is available most of the time to make adjustments.

How Much Water Is Needed?

A considerable amount of water is needed for plants and cleanup, and well or municipal water is best. Water consumption will be approximately 0.4 gal/ft^2 (42 l/m^2) of greenhouse space. For a 24 by 48 ft (7 by 14 m) greenhouse, this will be about 500 gal/day (1,900 l/day) during summer.

Is Security Necessary?

Protection of the greenhouse is necessary, especially in school situations. Whether a fence is needed or not will depend on location, glazing material, and the proximity of other people in the area. An alarm system is necessary for emergency conditions and can be fitted with a motion detector.

List of Participants

Joint Conference of the Southern Forest Nursery Association and the Northeastern Forest and Conservation Nursery Association July 12–15, 2004; Charleston, SC

Tim Adams
South Carolina Forestry Commission
PO Box 21707
Columbia, SC 29221
Tel: 803.896.8802

Leigh Allen
WSI
Hanger 209 Craig Field
Selma, AL 36701
Tel: 338.872.6002

Lisa Amick
South Carolina Forestry Commission
PO Box 21707
Columbia, SC 29221
Tel: 803.896.8910

Tom Anderson
Plum Creek Company
14444 Shubuta-Eucutta Road
Shubuta, MS 39360
Tel: 601.687.5761

Mike Arnette
IPCO
5594 Hwy 38 S
Blenheim, SC 29516
Tel: 800.222.1290

Jill Barbour
USDA Forest Service
National Tree Seed Laboratory
5675 Riggins Mill Road
Dry Branch, GA 31020
Tel: 478.751.3551

Richard Barham
73 Mill Run Terrace
Richmond Hill, GA 31324
Tel: 912.727.2523

Wayne Barrick
Peach Springs Nursery
1155 N FM 2869
Winnsboro, TX 75494
Tel: 903.629.3262

Susan Best
USDA Forest Service
320 Green Street
Athens, GA 30602
Tel: 706.559.4230

Bill Boeckman
Weyerhaeuser
2960 Columbia 11 East
Magnolia, AR 71753
Tel: 870.234.3537

Ralph Bower
Weyerhaeuser
3890 Hwy 28 West
Camden, AL 36726
Tel: 334.682.9882

Warren Bryant
White City Nursery
707 County Road 20 West
Verbena, AL 36091
Tel: 334.365.2488

Sam Campbell
Molpus Company
29650 Comstock Road
Elberta, AL 36530
Tel: 251.986.5210

Gary Cannon
202 W Carr Street
Colquitt, GA 39837
Tel: 229.758.3925

Stephen W Cantrell
South Carolina Forestry Commission
PO Box 219
Trenton, SC 29847
Tel: 803.275.3578

Bill Carey
Auburn University Nursery Cooperative
108 M White Smith Hall
Auburn University
Auburn, AL 36849
Tel: 334.844.4998

Bobby Catrett
Plum Creek Company
9292 Pine Grove Lane
Ward, AL 36922
Tel: 205.654.2625

Frank Corley
WSI
Hanger 209 Craig Field
Selma, AL 36701
Tel: 338.872.6002

Michelle Cram
USDA Forest Service
320 Green Street
Athens, GA 30602
Tel: 706.559.4245

Barbara Crane
USDA Forest Service
1720 Peachtree Road
Atlanta, GA 30309
Tel: 404.347.4039

Jim Crittenden
International Paper Company
Route 1
Box 1097
Shellman, GA 39886
Tel: 229.679.5640

Robert Cross Jr
International Paper Company
Route 1
Box 1097
Shellman, GA 39886
Tel: 229.679.5640

Tim Damico
Certis Company
9145 Guilford Road Suite 175
Cola, MD 21046
Tel: 301.483.3814

Tannis Danley
International Paper Company
PO Box 56
Bellville, GA 30414
Tel: 877.833.4760

Chuck Davey
Consultant
Department of Forestry
NC State University
Raleigh, NC 27695
Tel: 919.851.1168

Carl Davis
North Carolina Division of Forestry
762 Claridge Nursery Road
Goldboro, NC 27530
Tel: 919.731.7988

Gary Delaney
Louisiana Forest Seed Company
303 Forestry Road
Lecompte, LA 71346
Tel: 318.443.5026

Joe Douberly
Plum Creek Timber Company
1689 Nursery Road
Jesup, GA 31546
Tel: 912.427.4871

Thais Drezza
Auburn University Nursery Cooperative
Auburn University
Auburn, AL 36849
Tel: 334.844.4998

Kas Dumroese
USDA Forest Service
1221 S Main Street
Moscow, ID 83843
Tel: 208.883.2324

Scott Enebak
Auburn University Nursery Cooperative
108 M White Smith Hall
Auburn University
Auburn, AL 36849
Tel: 334.844.1028

Paul Ensminger
WSI Nursery
11306 Highway 411 S
Chatsworth, GA 30507
Tel: 706.334.2271

Larry Estes
State of Virginia
19127 Sandy Hill Road
Courtland, VA 23837
Tel: 804.834.2855

Barry Fawcett
Createc Corporation
PO Box 714
Findlay, OH 45840
Tel: 419.420.0029

Jeff Fields
Georgia Forestry Commission
PO Box 819
Macon, GA 31202
Tel: 478.751.3250

Larry Foster
International Paper Company
264 County Road 888
Selma, AL 36703
Tel: 334.872.5452

Craig Frazier
Alabama Forestry Commission
4165 Ross Road
Atmore, AL 36502
Tel: 251.368.8624

Chris Furman
2150 Commercial Drive
Frankfort, KY 40601

Richard Garrett
Maryland Department of Natural Resources
3424 Gallagher Road
Preston, MD 21655
Tel: 410.673.2467

Doug Gillett
Louisiana Forestry Commission
11 Frank Walker Road
Rayville, LA 71269
Tel: 318.345.7595

Steve Gilly
Florida Division of Forestry
Andrews Nursery
PO Drawer 849
Chiefland, FL 32644
Tel: 352.493.6096

Steve Godbehere
Hendrix & Dail, Inc
905 4th Street NW
Cairo, GA 39828
Tel: 229.387.4256

Becky Gonshorowski
Weyerhaeuser
169 Weyerhaeuser Road
Aiken, SC 29801
Tel: 803.649.0489

Chuck Goodowns
Certis Company
7610 SW 19th Place
Gainesville, FL 32607
Tel: 352.538.4471

Barb Graisy Adams
Bulldog Bag Company
15504 NE 91 Street
Vancouver, WA 98682
Tel: 360.896.9799

Kinney Hanchey
Louisiana Department of Forestry
PO Box 935
Deridder, LA 70634
Tel: 337.463.5509

Larry Hatcher
South Carolina Forestry Commission
Taylor Nursery
PO Box 219
Trenton, SC 29847
Tel: 803.275.3578

Selby Hawk
North Carolina Division of Forestry—Retiree
368 Settlemyer Road
Morganton, NC 28655
Tel: 828.437.2650

Bob Hawkins
Indiana Department of Natural Resources
2782 W County Road 540 S
Vallonia, IN 47281
Tel: 812.358.3621

Jim Heater
Silver Mountain Equipment
4672 Drift Creek Road SE
Sublimity, OR 97385
Tel: 503.769.7127

RD Hendricks, Jr
9818 Stilson Leefield Road
Statesboro, GA 30461
Tel: 912.842.2731

George Hernandez
USDA Forest Service
1720 Peachtree Road NW
Atlanta, GA 30309
Tel: 404.347.3554

Stanley Hinson
Southern Seed Company
PO Box 340
Baldwin, GA 30511
Tel: 706.778.4542

Jol Hodgson
Beaver Plastics
21499 Thornton Avenue
Maple Ridge, BC V4R 2G6
Canada
Tel: 604.476.1976

Marvin Holland
HB Fuller Company
1225 Lake Ridge Court
Grayson, GA 30017
Tel: 770.736.3987

David J Horvath
Illinois Department of Natural Resources
17855 N County Road 2400 E
Topeka, IL 61567
Tel: 309.535.2185

Greg Hoss
Missouri Division of Conservation
14027 Shafer Road
Licking, MO 65542
Tel: 573.674.3229

Kirk Howell
Consultant
PO Box 26
Auburn, GA 30011
Tel: 770.995.5242

Matthew Howell
University of Georgia
Athens, GA 30602
Tel: 404.347.3353

Jason Huffman
West Virginia State Nurseryman
101 Allison Drive
West Columbia, WV 25287
Tel: 304.675.1820

Bill Issacs
South Pine
PO Box 530127
Birmingham, AL 35253
Tel: 205.879.1099

Roger Jacob
Iowa Department of Natural Resources
2402 South Duff
Ames, IA 50010
Tel: 515.233.1161

Doug Jacobs
Hardwood Tree Improvement and Regeneration Center
715 West State Street
West Lafayette, IN 47907
Tel: 765.494.3608

Bryan Jordin
University of Georgia
Athens, GA 30602
Tel: 404.347.3353

Bob Karrfalt
USDA Forest Service
195 Marstellar Drive
West Lafayette, IN 47907
Tel: 765.494.3607

Rob Keck
National Wild Turkey Federation
PO Box 530
Edgefield, SC 29824
Tel: 803.637.3106

David Kinsey
Molpus Company
29650 Comstock Road
Elberta, AL 36530
Tel: 251.986.5210

Patricia Lima
Auburn University Nursery Cooperative
Auburn University
Auburn, AL 36849
Tel: 334.844.4998

Jimmy Lisenby
South Carolina Forestry Commission
Creech Greenhouse
5596 Tillghman Nursery Road
Wedgefield, SC 29168
Tel: 803.494.8110

Wayne Little
Weyerhaeuser
169 Weyerhaeuser Road
Aiken, SC 29801
Tel: 803.649.0489

Rob Lovelace
Lovelace Seeds
1187 Brownsmill Road
Elsberry, MO 63343
Tel: 573.898.2103

George Lowerts
International Paper Company
PO Box 1391
Savannah, GA 31402
Tel: 912.238.7689

Todd Martin
Hendrix and Dail Inc
2207 Twin Lakes Drive
Bainbridge, GA 39819
Tel: 229.387.4533

Charlie Matherne
Louisiana Forestry Commission
PO Box 1628
Baton Rouge, LA 70821
Tel: 225.925.4515

Dean McCraw
Rayonier
PO Box 456
Glennville, GA 30427
Tel: 912.654.4065

John McKinley
Mead/Westvaco
PO Box 739
Ravenel, SC 29470
Tel: 843.556.8391

Joshua McLaughlin
State of Virginia
19127 Sandy Hill Road
Courtland, VA 23837
Tel: 804.834.2855

Ken McNabb
Auburn University Nursery Cooperative
Auburn University
Auburn, AL 36849
Tel: 334.844.1044

Ken McQuage
Plum Creek Company
1032 Camp Lane
Hazelhurst, MS 39083
Tel: 601.894.1072

John McRae
International Paper Company
1550 Simpson Road
Odenville, AL 35120
Tel: 205.629.6461

Steve Meeks
Meeks Farm and Nursery Company
187 Flander Road
Kite, GA 31049
Tel: 912.536.3844

Brad Miller
Weyerhaeuser
169 Weyerhaeuser Road
Aiken, SC 29801
Tel: 803.649.0489

Horace Miller
Weyerhaeuser
1123 Dinah's Landing Road
Wahington, NC 27889
Tel: 252.948.2724

Mike Moman
Weyerhaeuser
PO Box 1391
New Burn, NC 28563
Tel: 252.633.7378

Ray Moody
South Carolina Forestry Commission
PO Box 21707
Columbia, SC 29221
Tel: 803.896.8863

Deb Moritz
Minnesota Department of Natural Resources
PO Box 95
Willow River, MN 55795
Tel: 218.372.3182

Adam Muckenfuss
Certis Company
328 SE Ridge Lane
Stuart, FL 34994
Tel: 772.781.2233

Joseph Muir
Maryland Department of Natural Resources
3424 Gallagher Road
Preston, MD 21655
Tel: 410.673.2467

Tim Mullins
North Carolina State University
Raleigh, NC 27695
Tel: 919.515.3168

Allan Murray
Arkansas Forestry Commission
1420 Hwy 391 N
North Little Rock, AR 72117
Tel: 501.907.2485

Al Myatt
830 NE 12th Avenue
Goldsby, OK 73093
Tel: 405.288.2385

Gary Nelson
International Paper Company
5594 Hwy 38 S
Blenheim, SC 29516
Tel: 843.528.3203

Tom Nielsen
Knud Nielsen Company
217 Park Street
Evergreen, AL 36401
Tel: 251.578.2900

Steven Oak
USDA Forest Service
1579 Brevard Road
Ashville, NC 28806
Tel: 828.257.4322

David Olsen
North Central Reforestation Inc
10466 405th Avenue
Evansville, MN 56329
Tel: 218.747.2622

Michelle Olsen
North Central Reforestation Inc
10466 405th Avenue
Evansville, MN 56329
Tel: 218.747.2622

Jason Parker
Hendrix and Dail, Inc
104 Westbrooke Drive
Statesboro, GA 30458
Tel: 229.387.1410

Mark Parrott
International Paper Company
686 Bullock County Road 28
Union Springs, AL 36089
Tel: 334.474.3229

Greg Pate
North Carolina Division of Forestry
762 Claridge Nursery Road
Goldboro, NC 27530
Tel: 919.731.7988

Jeremy Pinto
USDA Forest Service
1221 S Main Street
Moscow, ID 83843
Tel: 208.883.2324

Russ Pohl
Georgia Forestry Commission
PO Box 819
Macon, GA 31202
Tel: 478.751.3250

Randy Rentz
Louisiana Forestry Commission
PO Box 1388
Columbia, LA 71418
Tel: 318.649.7463

Jim Rigsby
Knud Nielson
PO Box 746
Evergreen, AL 36401
Tel: 251.578.2462

Lee Riley
USDA Forest Service
34963 Shoreview Road
Cottage Grove, OR 97424
Tel: 541.767.5723

Francisco Rodriguez
Auda Alemania 751
Los Angeles, CHILE
Tel: 564.31974666

Tommy Rogers
Florida State
PO Drawer 849
Chiefland, FL 32644
Tel: 352.493.6096

Terry Rucker
Boise Cascade
23194 Hwy 11
Deridder, LA 70634
Tel: 837.825.6329

Humberto Santos
Auburn University Nursery Cooperative
Auburn University
Auburn, AL 36849
Tel: 334.844.4998

Jerry Scott
Georgia Forestry Commission
PO Box 819
Macon, GA 31202
Tel: 478.751.3250

Greg Seabolt
Georgia Forestry Commission
PO Box 819
Macon, GA 31202
Tel: 478.751.3250

Doug Sharp
Plum Creek Company
161 N Macon Street
Jesup, GA 31545
Tel: 912.588.9798

Timothy Shoupe
North Carolina Division of Forestry
762 Claridge Nursery Road
Goldboro, NC 27530
Tel: 919.731.7988

Anne Smith
South Carolina Forestry Commission
PO Box 219
Trenton, SC 29847
Tel: 803.275.3578

Bobby Wayne Smith
North Carolina Division of Forestry
762 Claridge Nursery Road
Goldboro, NC 27530
Tel: 919.731.7988

Hunter Smith
Portco Packaging
3601 SE Columbia Way
Vancouver, WA 98661
Tel: 360.696.1641

Steve Smith
Weyerhaeuser
2960 Columbia 11 East
Magnolia, AR 71753
Tel: 870.234.3537

David South
Auburn University Nursery Cooperative
Auburn University
Auburn, AL 36849
Tel: 334.844.1022

David Sparkman
North Carolina Division of Forestry
762 Claridge Nursery Road
Goldboro, NC 27530
Tel: 919.731.7988

Dwight Stallard
State of Virginia
19127 Sandy Hill Road
Courtland, VA 23837
Tel: 804.834.2855

Tim Stewart
Temple-Inland
Route 2
Box 510
Jasper, TX 75951
Tel: 409.384.6164

Don Stringfield
Mead/Westvaco
PO Box 739
Ravenel, SC 29470
Tel: 843.556.8391

Eric Stuewe
Stuewe and Sons
2290 SE Kiger Island Drive
Corvallis, OR 97333
Tel: 541.757.7798

Robert Sweat
Sweat Company
3430 Summit Boulevard
Pensacola, FL 32503
Tel: 850.438.4155

John Taylor
USDA Forest Service
Suite 862s
1720 Peachtree Road NW
Atlanta, GA 30309
Tel: 404.347.2718

James Tule
Temple-Inland
229 North Bowie Street
Jasper, TX 75951
Tel: 409.383.2554

Brian Vachowski
USDA Forest Service
5785 Hwy 10 West
Missoula, MT 59808
Tel: 406.329.3935

Harry Vanderveer
Texas Forest Service
PO Box 617
Alto, TX 75925
Tel: 936.858.4202

Victor Vankus
USDA Forest Service
National Tree Seed Laboratory
5675 Riggins Mill Road
Dry Branch, GA 31020
Tel: 478.751.3551

Craig A Vansickle
Minnesota Department of Natural Resources
Badoura State Nursery
13885 Sate Hwy 64
Akeley, MN 56433
Tel: 218.652.2385

Steven Vongroven
Minnesota Department of Natural Resources
PO Box 95
Willow River, MN 55795
Tel: 218.372.3182

Lucy Walker
Weyerhaeuser
1123 Dinah's Landing Road
Wahington, NC 27889
Tel: 252.948.2724

Macy Wall
Portco Packaging
3601 SE Columbia Way
Vancouver, WA 98661
Tel: 360.696.1641

Mike Waxler
Weyerhaeuser
PO Box 1060
Hot Springs, AR 71902
Tel: 501.624.8494

Chase Weatherly
IPCO
186 Navada 420
Bluff City, AK 71722
Tel: 800.222.1270

Dennis Whitfield
Whitefield Manufacturing
PO Box 188
Mableton, GA 30126
Tel: 770.948.1212

Jim Wichman
Indiana Department of Natural Resources
2782 W County Road 540 S
Vallonia, IN 47281
Tel: 812.358.3621

Sam Wiggins
Knud Neilson Company
217 Park Street
Evergreen, AL 36401
Tel: 251.578.2900

Ryan Wilks
Hendrix and Dail, Inc
2351 Erskine Avenue
Charleston, SC 29414
Tel: 843.340.7472

Don Willis
Jiffy Performa
850 Widdifield Station Road
North Bay, ON P1B 8G2
Canada
Tel: 705.495.4781

Keith Windell
USDA Forest Service
5785 Hwy 10 West
Missoula, MT 59804
Tel: 406.329.3956

Ken Woody
Plum Creek Company
1032 Camp Lane
Hazelhurst, MS 39083
Tel: 601.894.1072

Western Forest and Conserevation Nursery Association
July 26–29, 2004; Medford, OR

Abbie Acuff
Potlatch Corporation
PO Box 1388
Lewiston, ID 83501
Tel: 208.799.1103
E-mail: Abbie.Acuff@potlatchcorp.com

Peggy Adams
Jamestown S'Klallam Tribe
1033 Old Blyn Highway
Sequim, WA 98382
Tel: 360.683.1109
E-mail: padams@jamestowntribe.org

Robert Adams
Hopi Tribe
PO Box 123
Kykotsmovi, AZ 86039
Tel: 928.738.0014
E-mail: Ppavatea@hopi.nsn.us

Sue Antiste
Confederated Salish and Kootenai Tribes
PO Box 155
Elmo, MT 59915
Tel: 406.849.5541
E-mail: kootni@centurytel.net

Amanullah Arbab
Navajo Forestry Department
PO Box 230
Fort Defiance, AZ 86504
Tel: 928.729.4007

Colleen Archibald
USDA Forest Service
JH Stone Nursery
2606 Old Stage Road
Central Point, OR 97502
Tel: 541.858.6131
E-mail: carchibald@fs.fed.us

Cor Baars
International Horticultural Technologies
PO Box 1035
Hollister, CA 95024
Tel: 831.637.1800
E-mail: cor@ihort.com

Elton Baldy
Hoopa Valley Tribal Forestry
PO Box 368
Hoopa, CA 95546
Tel: 530.625.4206
E-mail: elton@pcweb.net

James Barnett
USDA Forest Service
2500 Shreveport Hwy
Pineville, LA 71360
Tel: 318.473.7216
E-mail: jpbarnett@fs.fed.us

Allison Barrows
USDA Forest Service
Coeur d'Alene Nursery
3600 Nursery Road
Coeur d'Alene, ID 83815
Tel: 208.765.7439
E-mail: arbarrows@fs.fed.us

John Bartok
135 Pumpkin Hill Road
Ashford, CT 06278
Tel: 860.429.4842
E-mail: jbartok@rcn.com

George Bear
APEX Professional Products
JR Simplot
21035 SW Old Pacific Hwy
Sherwood, OR 97140
Tel: 503.538.5391
E-mail: george.bear@simplot.com

Dennis Becenti
Hopi Tribe
PO Box 123
Kykotsmovi, AZ 86039
Tel: 928.738.0018
E-mail: Ppavatea@hopi.nsn.us

Edwina Begay
Cold Springs Tribe
PO Box 209
Tollhouse, CA 93667
Tel: 559.855.5043

Ron Boerboom
Mountain View Growers, Inc
PO Box 99
Summerland, BC V0H 1Z0
Canada
Tel: 250.494.9467
E-mail: mviewgrowers@telus.net

Domenic Bongio
Scotia Pacific Company, LLC
PO Box 712
Scotia, CA 95565
Tel: 707.764.4241
E-mail: dbongio@scopac.com

Julie Brown
IFA Nurseries, Inc
136 Territorial Road NE
Canby, OR 97013
Tel: 503.266.1940

Frank Burch
USDA Forest Service
Sidney R Yates Federal Building
201 - 14th Street SW
Washington, DC 20250
Tel: 202.205.0946
E-mail: fburch@fs.fed.us

Katrina Burnside
Confederated Tribes of the Umatilla Indian Reservation
PO Box 638
Pendleton, OR 97801
Tel: 541.278.5298
E-mail: wildtechs@ctuir.com

Karen Burr
USDA Forest Service
Coeur d'Alene Nursery
3600 Nursery Road
Coeur d'Alene, ID 83815
Tel: 208.765.7396
E-mail: kburr@fs.fed.us

Robin Chimal
Mescalero Apache Tribe
PO Box 227
Mescalero, NM 88340
Tel: 505.464.4711

Roderick H Chimal
Bureau of Indian Affairs
PO Box 189
Mescalero, NM 88340
Tel: 505.464.4410

Michael Clee
Bulldog Bag Ltd
13631 Vulcan Way
Richmond, BC V6V 1K4
Canada
Tel: 604.273.8021
E-mail: mclee@bulldogbag.com

Arden Comanche
Mescalero Apache Tribe
PO Box 227
Mescalero, NM 88340
Tel: 505.464.4711

Tim Crockett
Washington Department of Natural Resources
Webster Nursery
PO Box 47017
Olympia, WA 98504
Tel: 360.753.5305

Rico Cruz
CTUIR
Eastern Oregon University
PO Box 638
Pendleton, OR 97801
Tel: 541.969.3664
E-mail: ricocruz@ctuir.com

Randolph Dahlin
3363 Robertson Road
Bellingham, WA 98226
Tel: 360.383.0446

Karl Dalla Rosa
USDA Forest Service
MS 1123, 1400 Independence Avenue SW
Washington, DC 20250-1123
Tel: 202.205.6206
E-mail: kdallarosa@fs.fed.us

Jude Danielson
USDA Forest Service
Dorena Genetic Resource Center
34963 Shoreview Road
Cottage Grove, OR 97424
Tel: 541.767.5711
E-mail: jdanielson@fs.fed.us

Dale Darris
USDA Natural Resources Conservation Service
Plant Materials Center
3415 NE Granger Avenue
Corvallis, OR 97330
Tel: 541.757.4812 x 101
E-mail: Dale.Darris@or.usda.gov

David Davis
USDA Forest Service
JH Stone Nursery
2606 Old Stage Road
Central Point, OR 97502
Tel: 541.858.6180

Ronald Davis
Turtle Mountain Band of Chippewa Indians
PO Box 570
Belcourt, ND 58316
Tel: 701.477.2654
E-mail: chippewaforest@yahoo.com

R Alexander Day
Department of Conservation and Natural Resources-Bureau of Forestry
Penn Nursery
137 Penn Nursery Road
Spring Mills, PA 16875
Tel: 814.364.5150
E-mail: rday@state.pa.us

Graig Delbol
Althouse Nursery
5410 Dick George Road
Cave Junction, OR 97523
Tel: 541.592.2395

Edward Doney
Fort Belknap Reservation
PO Box 159
Harlem, MT 59526
Tel: 406.353.2607

Linda Duffy
USDA Forest Service
Rogue River National Forest
645 Washington Street
Ashland, OR 97520
Tel: 541.552.2903
E-mail: lduffy@fs.fed.us

Kas Dumroese
USDA Forest Service
1221 South Main Street
Moscow, ID 83843
Tel: 208.883.2324
E-mail: kdumroese@fs.fed.us

Aram Eramian
USDA Forest Service
Coeur d'Alene Nursery
3600 Nursery Road
Coeur d'Alene, ID 83815
Tel: 208.765.7392
E-mail: aeramian@fs.fed.us

Jim Fischer
Silver Mountain Enterprises, LLC
4672 Drift Creek Road
Salem, OR 97385
Tel: 503.769.7133
E-mail: jimf@silvermtnnursery.com

Clark Fleege
USDA Forest Service
15169 E Highway 21
Boise, ID 83716
Tel: 208.343.1977
E-mail: cfleege@fs.fed.us

Randall Friedlander
Colville Tribes
PO Box 150
Nespelem, WA 99155
Tel: 509.634.2332

Nicolas Garcia
3250 Road 1
Redwood Valley, CA 95470
Tel: 707.485.0361

Ellen Goheen
USDA Forest Service
JH Stone Nursery
2606 Old Stage Road
Central Point, OR 97502
Tel: 541.858.6126
E-mail: egoheen@fs.fed.us

Barb Graisy
Bulldog Bag Ltd
15504 NE 91 Street
Vancouver, WA 98682
Tel: 360.896.9799
E-mail: bgraisy@comcast.net

Vic Guerrero
CNMI Government
Box 7255 SVRB
Saipan, MP 96950 USA
Tel: 670.256.3320
E-mail: victordlg@gtepacifica.net

Rosemary Guttridge
USDA Forest Service
3502 Highway 30
LaGrande, OR 97850
Tel: 541.962.8514
E-mail: rguttridge@fs.fed.us

Diane Haase
Oregon State University
Forest Science
321 Richardson Hall
Corvallis, OR 97331
Tel: 541.737.6576
E-mail: diane.haase@oregonstate.edu

Gary Hartman
International Horticultural Technologies
PO Box 1035
Hollister, CA 95024
Tel: 831.637.1800
E-mail: gary@ihort.com

Tom Harvie
Pacific Regeneration Technologies
2825 Burce Road
Black Creek, BC V9J 1B7
Canada
Tel: 250.287.0366
E-mail: tom.harvie@prtgroup.com

Jeanne Hendrix
Yurok Tribe
15900 N Hwy 101
Klamath, CA 95548
Tel: 707.482.2841 x 226
E-mail: jmhendrix13@aol.com

George Hernandez
USDA Forest Service
1720 Peachtree Road NW, #850
Atlanta, GA 30309
Tel: 404.347.3554
E-mail: ghernandez@fs.fed.us

Jol Hodgson
Beaver Plastics Ltd
21499 Thornton Avenue
Maple Ridge, BC V4R 2G6
Canada
Tel: 604.476.1976
E-mail: tjhodgson@shaw.ca

Anthony Holland
USDA Forest Service
PO Box 340
Watersmeet, MI 49969
Tel: 906.358.4523

Russ Holzhauser
Wind River Seed
3075 Lane 51 1/2
Manderson, WY 82432
Tel: 307.568.3361
E-mail: russ@windriverseed.com

Theodora Homewytewa
Hopi Tribe
804 North Beaver Street
Flagstaff, AZ 86001
Tel: 520.213.0195

Rick Hunter
Cold Springs Tribe
PO Box 209
Tollhouse, CA 93667
Tel: 559.855.5043

Jan Huntsburger
USDA Forest Service
Coeur d'Alene Nursery
3600 Nursery Road
Coeur d'Alene, ID 83815
Tel: 208.765.7429

Douglass Jacobs
Purdue University
Department of Forestry and Natural Resources
1159 Forestry Building
West Lafayette, IN 47907
Tel: 765.494.3608
E-mail: djacobs@fnr.purdue.edu

Randall Jones
USDA, AMS, Livestock & Seed Program
1400 Independence Avenue SW
Washington, DC 20250
Tel: 202.720.5705
E-mail: randall.jones@usda.gov

Tom Jopson
Cal Forest Nurseries
PO Box 719
Etna, CA 96027
Tel: 530.467.5211
E-mail: calforest@sisqtel.net

Sherise Jurries
Potlatch Corporation
PO Box 1388
Lewiston, ID 83501
Tel: 208.799.1119
E-mail: Sherise.Jurries@potlatchcorp.com

Bob Karrfalt
USDA Forest Service
Wright Forestry Center
1007 North 725 West
West Lafayette, IN 47907
Tel: 765.583.3512
E-mail: rkarrfalt@fs.fed.us

Randy Kaufman
Lone Peak Conservation Center
271 W Bitterbush Lane
Draper, UT 84020
Tel: 801.571.0900

Pat Kincaid
PO Box 3674
Durango, CO 81302
Tel: 970.259.4057

Jerry Kingbird
Ponemah Elementary School
PO Box 39
Ponemah, MN 56666
Tel: 218.554.7337

John Kitchen
Pacific Regeneration Technologies, Inc
355 Burrard Street, #410
Vancouver, BC V6C 2G8
Canada
Tel: 604.687.1404
E-mail: john.kitchen@prtgroup.com

Ted Koellmann
Phillips Soil Products
PO Box 986
Molalla, OR 97038
Tel: 503.519.4675
E-mail: mrgr8dirt@aol.com

Bradley Lajeunesse
Redlake DNR
PO Box 643
Redby, MN 56671
Tel: 218.679.3310

Tom Landis
USDA Forest Service
JH Stone Nursery
2606 Old Stage Road
Central Point, OR 97502
Tel: 541.858.6166
E-mail: nurseries@aol.com

Dennis Longknife
Fort Belknap Indian Community
RR #1, Box 66
Harlem, MT 59526
Tel: 406.353.8431
E-mail: dlongknife@hotmail.com

James Manglona
Department of Lands and Natural Resources
PO Box 924
Rota, MP 96951
Tel: 670.532.9494
E-mail: jamesone@vzpacifica.net

Jeff Masga
Department of Lands and Natural Resources
PO Box 924
Rota, MP 96951
Tel: 670.532.9494
E-mail: jamesone@vzoacifica.net

Haley McCarty
Makah Tribe
PO Box 116
Neah Bay, WA 98357
Tel: 360.645.3067
E-mail: vantilborg@excite.com

Doug McCreary
University of California
8279 Scott Forbes Road
Browns Valley, CA 95918
Tel: 530.639.8807
E-mail: ddmccreary@ucdavis.edu

Manuel Morales
Fort Belknap College
PO Box 159
Harlem, MT 59526
Tel: 406.353.8431

Joseph Myers
USDA Forest Service
Coeur d'Alene Nursery
3600 Nursery Road
Coeur d'Alene, ID 83815
Tel: 208.765.7387
E-mail: jfmyers@fs.fed.us

Duane Nelson
USDA Forest Service
1323 Club Drive
Vallejo, CA 94592
Tel: 707.562.8687
E-mail: dnelson03@fs.fed.us

Randy Niman
USDA Forest Service
428 W Woodin Avenue
Chelan, WA 98816
Tel: 509.682.2576
E-mail: rniman@fs.fed.us

Paul O'Neill
Beaver Plastics Ltd
12150 - 160th NW Street
Edmonton, AB T5V 1H5
Canada
Tel: 888.453.5961
E-mail: growerinfo@beaverplastics.com

Ron Overton
USDA Forest Service
Purdue University
PFEN, 715 West State Street
West Lafayette, IN 47907
Tel: 765.496.6417
E-mail: overtonr@purdue.edu

Peyton Owsten
PO Box 1006
Neskowin, OR 97149

Jeremy Pinto
USDA Forest Service
1221 South Main Street
Moscow, ID 83843
Tel: 208.883.2352
E-mail: jpinto@fs.fed.us

Peggy Pyke-Thompson
Akwesasne Mohawk Nation
PO Box 278
Roosevelton, NY 13683
Tel: 613.933.0290
E-mail: peggyp@sympatico.ca

Nita Rauch
USDA Forest Service
Bend Seed Extractory
63095 Deschutes Market Road
Bend, OR 97701
Tel: 541.383.5646
E-mail: nrauch@fs.fed.us

Michelle Reynolds
Red Lake Band of Chippewa
PO Box 643
Redlake, MN 56670
Tel: 218.679.3310

Lee Riley
USDA Forest Service
Dorena Genetics Resource Center
34963 Shoreview Road
Cottage Grove, OR 97424
Tel: 541.767.5723
E-mail: leriley@fs.fed.us

Robin Rose
Oregon State University
College of Forestry
Corvallis, OR 97331
Tel: 541.737.6580
E-mail: robin.rose@orst.edu

William Ross
Hastings Smith River Nursery
PO Box 250
Smith River, CA 95567
Tel: 707.487.3775
E-mail: srtrees@gte.net

Glenda Scott
USDA Forest Service
PO Box 7669
Missoula, MT 59807
Tel: 406.329.3122
E-mail: glscott@fs.fed.us

Nancy Shaw
USDA Forest Service
316 E Myrtle
Boise, ID 83702
Tel: 208.373.4360
E-mail: nshaw@fs.fed.us

Cecilia Sheoships
Confederated Tribes of the Umatilla Indian Reservation
PO Box 638
Pendleton, OR 97801
Tel: 541.278.5298
E-mail: wildtechs@ctuir.com

Cheryl Shippentower
CTUIR
Eastern Oregon University
PO Box 638
Pendleton, OR 97801
Tel: 541.276.3449
E-mail: cherylshippentower@ctuir.com

Lydia Smith
IFA Nurseries, Inc
136 NE Territorial Road
Canby, OR 97013
Tel: 503.266.1940

Mike Smith
Washington Department of Natural Resources
Webster Nursery
PO Box 47017
Olympia, WA 98504-7017
Tel: 360.753.5305

Jennifer Smoke
Akwesasne Freedom School
PO Box 290
Roosevelton, NY 13683
Tel: 518.358.2073

Michael Sockyma
Hopi Tribe
804 North Beaver Street
Flagstaff, AZ 86001
Tel: 928.213.0195

Shawn Speidel
Lawyer Nursery
7515 Meridian Road SE
Olympia, WA 98513
Tel: 360.456.1839
E-mail: shawns@lawyernursery.com

Dave Stearns
IFA Nurseries, Inc
136 NE Territorial Road
Canby, OR 97013
Tel: 503.266.1940
E-mail: ifanursery@aol.com

David Steinfeld
USDA Forest Service
JH Stone Nursery
2606 Old Stage Road
Central Point, OR 97502
Tel: 541.858.6101
E-mail: dsteinfeld@fs.fed.us

Sandra Stone
USDA Forest Service
1323 Club Drive
Vallejo, CA 94510
Tel:707.562.8918
E-mail: sstone01@fs.fed.us

Sonia Tamez
USDA Forest Service
1323 Club Drive
Vallejo, CA 94592
Tel: 707.562.8919
E-mail: stamez@fs.fed.us

Max Taylor
Hopi Tribe
PO Box 123
Kykotsmovi, AZ 86039
Tel: 928.738.0014
E-mail: Ppavatea@hopi.nsn.us

Dawn Thomas
Intertribal Group
PO Box 70
Pablo, MT 59855
Tel: 406.275.4798

Michael Thompson
Akwesasne Mohawk Nation
PO Box 278
Roosevelton, NY 13683
Tel: 613.933.0290

Roger Thompson
Akwesasne Mohawk Nation
PO Box 278
Roosevelton, NY 13683
Tel: 613.933.0290

Patricia Trimble
USDA Forest Service
Placerville Nursery
2375 Fruitridge Road
Camino, CA 95709
Tel: 530.642.5025
E-mail: ptrimble@fs.fed.us

Dave Trotter
Surrey, BC
Canada
Tel: 604.936.3192
E-mail: dtrotter@telus.net

Brian Vachowski
USDA Forest Service
Missoula Technology and Development Center
5785 Highway 10 West
Missoula, MT 59808
Tel: 406.329.3935
E-mail: bvachowski@fs.fed.us

Evert Van Eerden
NewGen Forestry Ltd
5635 Forest Hill Road
Victoria, BC V9E 2A8
Canada

Kevin Vander Ploeg
Plantech Control Systems
PO Box 75068
White Rock, BC V4B 4X4
Canada
Tel: 604.541.1234
E-mail: kevinv@viscon-na.com

Rae Watson
USDA Forest Service
JH Stone Nursery
2606 Old Stage Road
Central Point, OR 97502
Tel: 541.858.6131
E-mail: rewatson@fs.fed.us

Ken Wearstler
USDA Forest Service
JH Stone Nursery
2606 Old Stage Road
Central Point, OR 97502
Tel: 541.858.6101

David Weskamp
Yurok Tribe
15900 Hwy 101
Klamath, CA 95548
Tel: 707.482.2841 x 242
E-mail: davew@harborside.com

Ryan West
RECON Native Plants
1755 Saturn Boulevard
San Diego, CA 92154
Tel: 619.778.6205
E-mail: rwest@recon-us.com

Bruce White
Red Lake Band of Chippewa
PO Box 643
Redby, MN 56670
Tel: 218.679.3310

Diane White
USDA Forest Service
Rogue River/Siskiyou National Forests
Federal Building
333 W 8th Street, Box 520
Medford, OR 97501
Tel: 541.858.2295
E-mail: dewhite01@fs.fed.us

Gloria Whitefeather-Spears
Red Lake Band of Chippewa
PO Box 643
Redby, MN 56670
Tel: 218.679.3310
E-mail: gspears@paulbunyon.net

Tina Williams
Cold Springs Tribe
PO Box 209
Tollhouse, CA 93667
Tel: 559.855.5043
E-mail: coldspringsepa@hotmail.com

Randy Wolfe
Washington Department of Natural Resources
Webster Nursery
PO Box 47017
Olympia, WA 98504-7017
Tel: 360.753.5305

Diana Yupe
USDA Forest Service
324 25th Street
Federal Building
Ogden, UT 84401
Tel: 801.625.5370
E-mail: dyupe@fs.fed.us

RMRS
ROCKY MOUNTAIN RESEARCH STATION

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Flagstaff, Arizona
Fort Collins, Colorado*
Boise, Idaho
Moscow, Idaho
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Logan, Utah
Ogden, Utah
Provo, Utah

*Station Headquarters, 240 West Prospect Road, Fort Collins, CO 80526