Tree Planters' Notes

United States Department of Agriculture
Forest Service

Fall 2015
Volume 58, Number 2

Dear TPN Reader

You will notice that this issue is longer than usual. This is because it includes papers that were presented at the 2014 annual nursery meetings.

- Joint Meeting of the Northeast Forest and Conservation Nursery Association and Southern Forest Nursery Association (Williamsburg, VA, July 21–24, 2014).
- Joint Meeting of the Western Forest and Conservation Nursery Association, the Intermountain Container Seedling Growers Association, and the Intertribal Nursery Council (Boise, ID, September 9–11, 2014).

Since the "Meeting of Forest Tree Nurserymen" held January 17–18, 1949, in Seattle, WA, proceedings papers have been published to share technology and expertise among nursery growers and managers around the country. All of these proceedings are available online at http://www.rngr.net/publications/proceedings/. Starting with these 2014 proceedings, we have decided to publish the papers in *Tree Planters' Notes* (TPN). The papers will still be identified as papers that were presented at the nursery meetings, and they will still be listed online in the National Nursery Proceedings section of the RNGR Web site, but their citation is now in TPN. Publishing in TPN results in many advantages: (1) publication will occur 6 to 12 months sooner; (2) papers will have a much wider distribution in TPN than they did in the proceedings; (3) because TPN is published in full color, proceedings papers can now have more descriptive photos and figures; and (4) in addition to the normal editing, TPN undergoes a second edit for consistent format and grammar, resulting in a more polished, professional publication. In all, this change will be a win-win for both authors and readers!

This issue contains a total of 14 articles, including a profile of Maryland's past and present tree planting activities for TPN's State-by-State series, the annual report on estimated seedling production and outplanted acres by State and by region, five papers presented at the Williamsburg, VA, meeting, and five papers presented at the Boise, ID, meeting.

Best wishes to all of you for a pleasant fall and winter season!

Diane

Give fools their gold, and knaves their power;
let fortune's bubbles rise and fall;
who sows a field, or trains a flower,
or plants a tree, is more than all.
~ John Greenleaf Whittier

***Tree Planters' Notes* (TPN) is dedicated to technology transfer and publication of information relating to nursery production and outplanting of trees and shrubs for reforestation, restoration, and conservation.**

TPN is sponsored by the Cooperative Forestry Staff of the U.S. Department of Agriculture (USDA), Forest Service, State and Private Forestry Deputy Area, in Washington, DC. The Secretary of Agriculture has determined that the publication of this periodical is necessary in the transaction of public business required by law of this Department.

Editor: Diane L. Haase

TPN accepts both technical and research articles; each is reviewed by the editor and/or anonymous referees. Please see the Guidelines for Authors at the end of the journal for details about editorial policy, formatting, style, and submission. Guidelines can also be accessed online at http://www.rngr.net/publications/tpn/author_guidelines.

Individual authors are responsible for the accuracy of the material in their respective articles. The mention of commercial products in this publication is solely for the information of the reader, and endorsement is not intended by the Forest Service or USDA.

On occasion, this publication reports information involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended. Caution: pesticides can injure humans, domestic animals, desirable plants, and fish and other wildlife if they are not handled or applied properly. Be sure to read and understand all label instructions. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

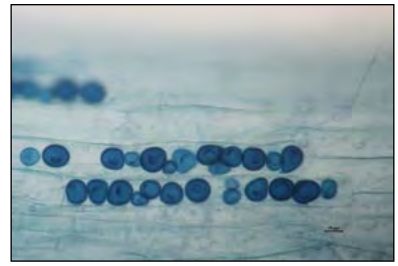
Web site: http://www.rngr.net/publications/tpn

E-mail: DLHaase@fs.fed.us

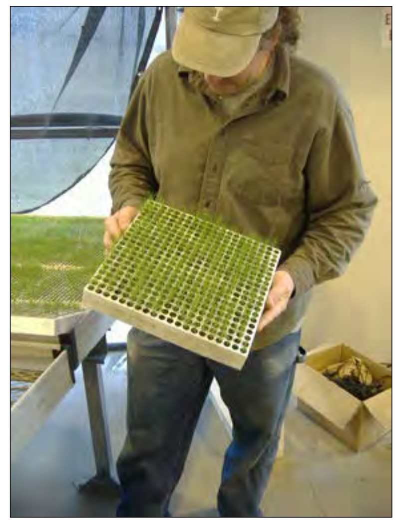
Printed on recycled paper.

Fall 2015

Contents



SEE PAGE 37



SEE PAGE 50

Author guidelines are available at http://www.rngr.net/publications/tpn/author_guidelines.

Forestry and Tree Planting in Maryland

Daniel Rider

Forest Stewardship and Utilization Program Manager, Maryland Department of Natural Resources Forest Service, Annapolis, MD

Abstract

After nearly four centuries of harvesting and clearing for agricultural and urban expansion, Maryland has 2.5 million ac (1.0 million ha) of forest covering approximately 43 percent of the total land area; most of these forests are considered "timber land."

The physiography of Maryland combines features from both northern and southern latitudes, resulting in a diversity of forest compositions. Most of Maryland's forests are hardwood types; 11 percent of the State's forests are pine. The most common species found in Maryland is red maple, and its dramatic rise in frequency is directly attributable to the absence of fire in the landscape. Uneven-aged silviculture is most prevalent, although even-aged management is commonly practiced in pine-producing areas. State nursery operations formally began in 1914, and, today, the nursery produces more than 3 million bareroot seedlings annually, representing 40 to 50 species. Numerous State and Federal programs support tree planting by offering technical and financial assistance. Land parcel sizes are trending smaller, which will challenge the ability to perform needed silviculture activities on greater portions of the landscape in the future.

Introduction

Maryland is often characterized as "America in miniature" because of its diverse physiography, history, and cultures, all resembling, in some aspect, the places and peoples found elsewhere in the United States. A visitor to Maryland can encounter within a day's drive hardwood-covered mountains; pine flats abutting sandy ocean beaches; vast forests; expansive agricultural districts dotted with small woodlots; and sprawling, tree-lined suburban complexes surrounding major urban centers. The central feature of Maryland's geography is the Chesapeake Bay, the largest estuary in the United States, which has enormous influence on the economy and ecology of Maryland and its forests. All of these elements have shaped the extent and composition of Maryland's forest resources.

Maryland's 2.5 million ac (1.0 million ha) of forest cover approximately 43 percent of the total land area (figure 1), and most (95 percent) of these forests are considered timber land (Lister et al. 2011). Moreover, 76 percent of these forests are privately owned, with most owners being families and individuals (Lister et al. 2011).

Maryland's Forest History

Colonization of Maryland began in earnest in 1634. Because the Chesapeake Bay region was interlaced with deep waterways coursing through highly fertile lands ideal for raising crops to export back to England, the earliest successful efforts to colonize North America were focused on the region that today is Virginia and Maryland. Forests were cleared for agricultural improvements, and the resultant timber products were heavily used as fuel and further refined into lumber and poles for boats, houses, barns, shops, bridges, roadways, forts, and nearly anything else needed to be made and too expensive to import. Wood was a major export commodity alongside tobacco, fish, and game hides (Middleton 1953). Later, as utilization technologies improved, fine crafts such as furniture and architectural millwork developed into highly respected trades, with demand for American products increasing in fine parlors throughout Europe (Middleton 1953). No less important, but having much less glamour, the utilitarian trades of cratings, cooperages, wagons, tanning, shingles, and various specialties of lumber manufacture all became major uses of forests (Besley and Dorrance 1919). For example, boatbuilders especially prized white oak and Atlantic white cedar (*Chamaecyparis thyoides* [L.] Britton, Sterns & Poggenb.). Loblolly pine and yellow poplar were the choice species for general construction. It is interesting that red maple, a very common species today, was scarce in most forests because of the ubiquitous use of fire, first by the Native Americans to keep forest undergrowth managed, and later by the colonists in combination with grazing to clear forests for conversion to tobacco and grain fields.

This trend of forest clearing for agricultural expansion continued throughout the 18th century and peaked in the 1830s. As the land was cleared, many of the smaller rivers silted in to the point of eliminating their use as transportation networks; however, by then, the inland population centers had grown

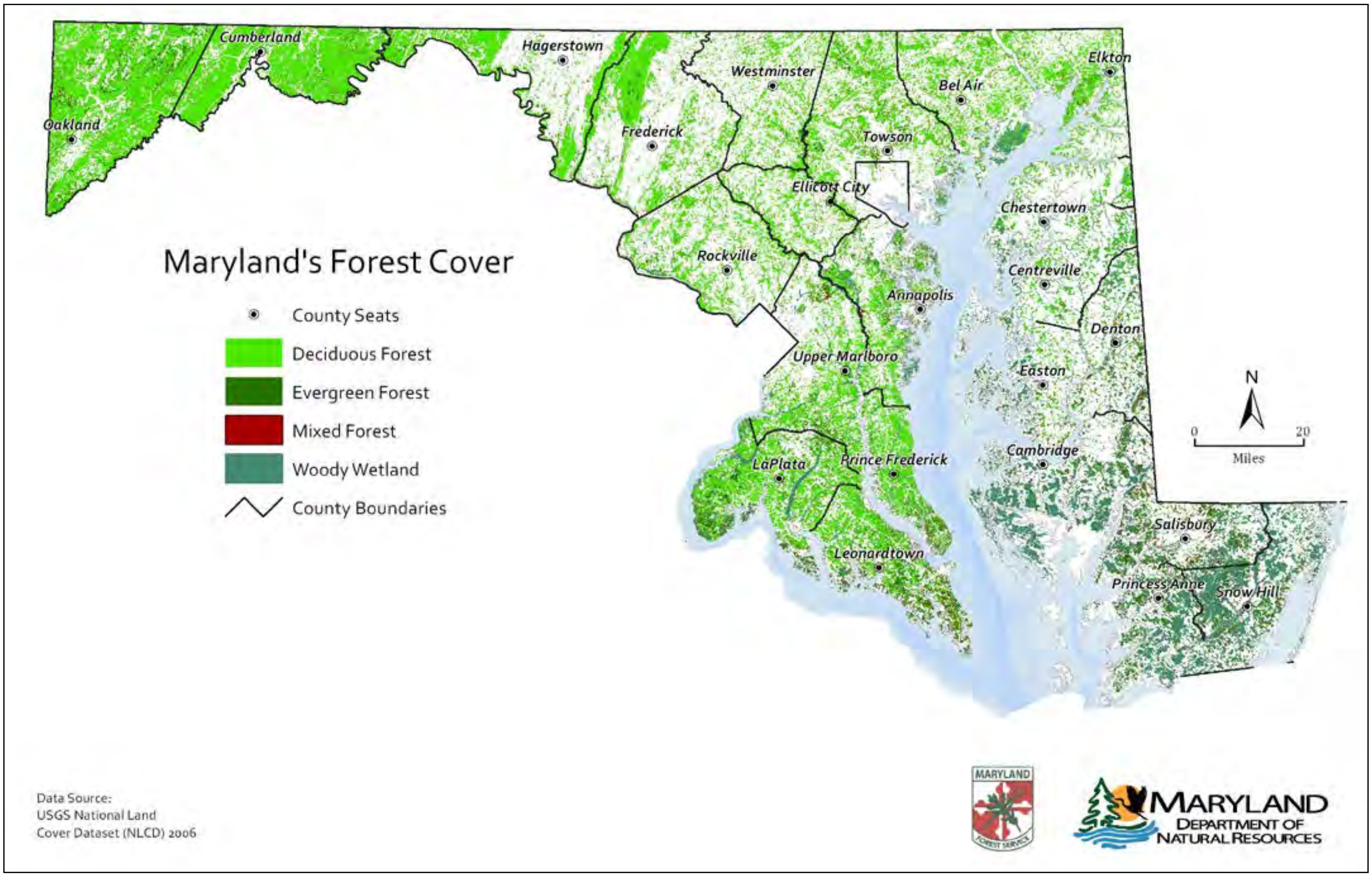


Figure 1. Maryland's forest cover. Source: U.S. Geological Survey National Land Cover Dataset (2006) updated by Maryland Forest Service (2013)

and adequate roadways directed commerce to the larger cities with deeper ports. By the mid-19th century, railroad networks rivaled shipping as bulk transportation networks. The rise of the railroad is significant to Maryland's forest history because that industry also spurred the demand for iron and the charcoal fuel needed to smelt the raw iron ore. Charcoal-fired furnaces were found throughout all of Maryland, with the larger furnaces in central and northern parts of the State providing steady, lucrative markets for fuel wood that lasted for decades and ultimately resulted in the clearing of tens of thousands of forested acres.

By 1914, 2.2 million ac (890,312.0 ha) of Maryland's forest supported 3.8 billion board feet (9.0 million m^3) of timber, which, in turn, fed a highly respected and valued industry of 800 sawmills, more than 300 wood-based manufacturers, and several ancillary businesses (Besley 1916, Besley and Dorrance 1919). Significant even by today's standards, 16,790 people relied on forest products for their wage, making it the second largest single industry in the State (Besley and Dorrance 1919). Loggers produced 229 million board feet (540,380 m^3) of logs, with hardwoods comprising 129 million board feet (304,405 m^3) and pine accounting for the other 100 million board feet (235,975 m^3) (Besley and Dorrance 1919). Lumber products accounted for only 40 percent of the annual timber harvest, with most of the harvest (60 percent) processed into pulpwood, railroad ties, piling, cordwood (i.e., fuel wood), tanbark, staves, shingles, lath, and charcoal (Besley and Dorrance 1919).

Today, 100 years later, Maryland still has roughly the same acreage of forest (2.5 million ac [approximately 1.0 million ha]) (figure 1), but these forests harbor a fivefold increase of timber (more than 22.0 billion board feet [5.2 million m^3]) (Lister et al. 2011). The annual growth rate has almost tripled during the past century, exceeding the goal first espoused by Maryland's first State forester, Fred Besley, when he proclaimed that the "production of Maryland's forests might be raised 100 percent" (Rider 2006). Yearly harvest volumes remain relatively constant at approximately 200 million board feet (472,000 m^3), and yet annual growth exceeds removals by at least 25 percent (Lister et al. 2011, Rider 2006). Ranked by highest volume of standing growing stock inventory, the principal commercial species include yellow poplar, red maple, loblolly pine, white oak, sweetgum, black cherry, and various species of red oak (Frieswyk 2001). Manufacturing still remains a vital component to Maryland's welfare, with the wood industries continuing as major players in the manufacturing sector (Rider 2006). Statewide, wood industries employ in excess of 10,000 people in 1,843 operations, which is 8 percent of all manufacturing jobs in the State (Rider 2012).

Forest Distribution and Composition

The physiography of Maryland combines features from both northern and southern latitudes, resulting in an interesting mix of forest compositions. For example, native stands of red spruce (*Picea rubens* Sarg.) dominate the high-elevation mountains of far western Maryland, while bald cypress (*Taxodium distichum* [L.] Rich.) dominate the most southern and eastern regions. Both of these forest types are minor in extant, but their existence demonstrates the wide range of site conditions resulting from the combination of latitude and elevation across five physiographic regions (i.e., Allegheny Plateau, Ridge and Valley, Piedmont, Upper Coastal Plain, and Lower Coastal Plain) within a span of just 250 mi (400 km) (figure 2).

Western Maryland (extending from Frederick County west to the State border) is very mountainous and forests are the principal land use. Although agriculture is present in western Maryland, it is largely confined to valley floors. Central Maryland is a rolling landscape typical of the Piedmont and is heavily cleared to accommodate agriculture and urban centers. Forests in the central part of the State are typically confined to riparian areas or small woodlots associated with farms (usually in areas too rocky to farm). Yellow poplar (*Liriodendron tulipifera* L.), oaks (*Quercus* spp.), red maple (*Acer rubrum* L.), and hickory (*Carya* spp.) are common tree species. Southern Maryland (loosely defined as the area east of Washington, DC, and south of Annapolis, MD) has deeper, less rocky soils; the more fertile soils are farmed and the less fertile, gravelly soils are typically forested with white oak (*Q. alba* L.), Virginia pine (*Pinus virginiana* Mill.), and yellow poplar. Some parts of southern Maryland produce stands of loblolly pine (*P. taeda* L.) and sweetgum (*Liquidambar styraciflua* L.) that rival those found in forests farther south. The Eastern Shore (land to the east of the Chesapeake Bay and west of the Atlantic Ocean) supports a mixture of hardwoods, such as yellow poplar, sweetgum, red maple, and various oak species, in its northern section, but its southern section is very similar to coastal plain forests of the southeast, with loblolly pine, sweetgum, and red maple.

The most common species found in Maryland is red maple (figure 3), and its dramatic rise in frequency is directly attributable to the absence of fire in the landscape (Lister et al. 2011). Because Maryland is the fifth most densely populated State in the United States, liability issues related to smoke and fire damage have virtually eliminated the use of fire as a management tool. Meanwhile, oaks have shown a steady decline in the past few decades (Lister et al. 2011). A lack of oak recruitment appears to be the cause for this decline. Yellow poplar has increased steadily during the same period while loblolly pine abundance has remained constant (Lister et al. 2011).

Regional differences reflect the physiographical influences of landscape position, soil type, and localized weather effects. Sugar maple (*Acer saccharum* Marshall), black cherry (*Prunus*

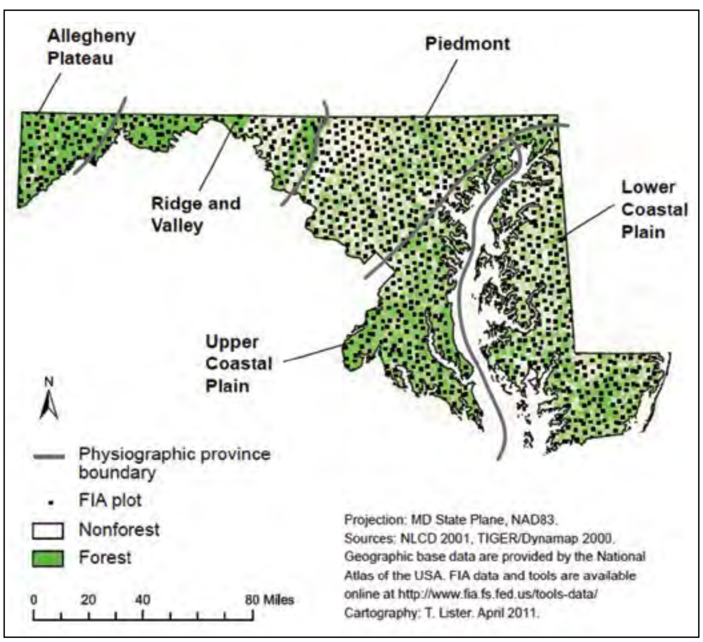


Figure 2. Physiographic provinces of Maryland. Source: Lister et al. (2011)

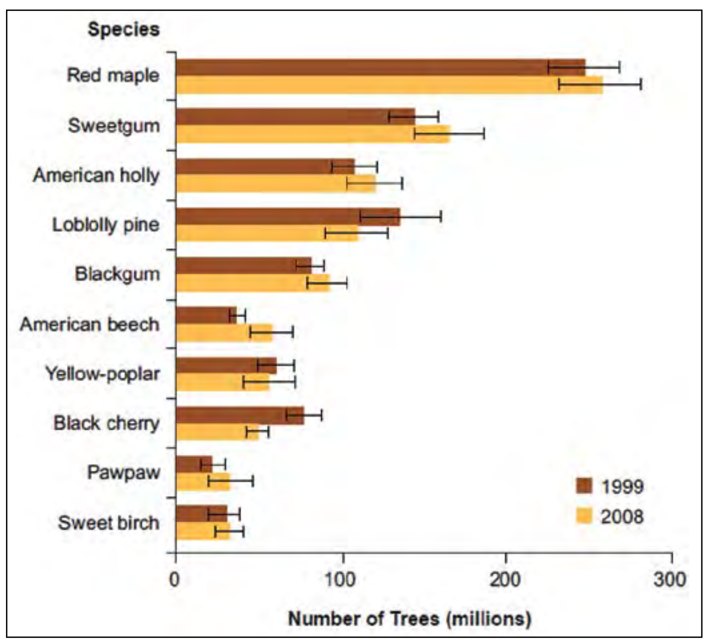


Figure 3. Relative abundance of timber species in Maryland. Source: Lister et al. (2011)

serotina Ehrh.), and northern red oak (*Quercus rubra* L.) are of superior form and quality in the far western portion of western Maryland, where the growing season is relatively short, cool, and wet. North-facing cove sites with deep and rich soils produce stands of trees exhibiting phenomenal timber qualities that are sought by savvy buyers from the world over. The coastal plain of the Eastern Shore has a longer, hotter growing season and the alluvial silts and sands are generally very low-lying and poorly drained, resulting in conditions highly favorable to loblolly pine and sweetgum. Maryland exhibits the northernmost limit of the natural range of loblolly pine, and many consumers greatly prefer the dense wood habit of Maryland grown pine compared with that of fast growing loblolly pines in the Deep South.

Forest Management

The Maryland Forest Service manages more than 200,000 ac (80,930 ha) of designated State forest (figure 4), but most forest lands are privately owned. Most of Maryland's forests are hardwood types; only 11 percent of Maryland's forests are pine. That fact, combined with a deep cultural aversion toward clearcutting among loggers and landowners alike, results in uneven-aged management of hardwoods to be the prevalent silvicultural system employed throughout most of Maryland. In stark contrast, forest management in the pine areas of the lower Eastern Shore follows a "clear-cut—plant—thin" silvicultural system typical of southern yellow pine management. Statewide, only about 20 percent of the 10,000 ac (4,000 ha) harvested annually are clearcut. Pulpwood markets are available throughout all of Maryland, but nowhere are they the dominant market driver. Sawtimber is clearly the mainstay of forest markets and, therefore, most landowners retain their timber for relatively long rotations, with pulpwood production incidental to sawtimber harvests or from mid-rotation thinnings in the pine-growing regions.

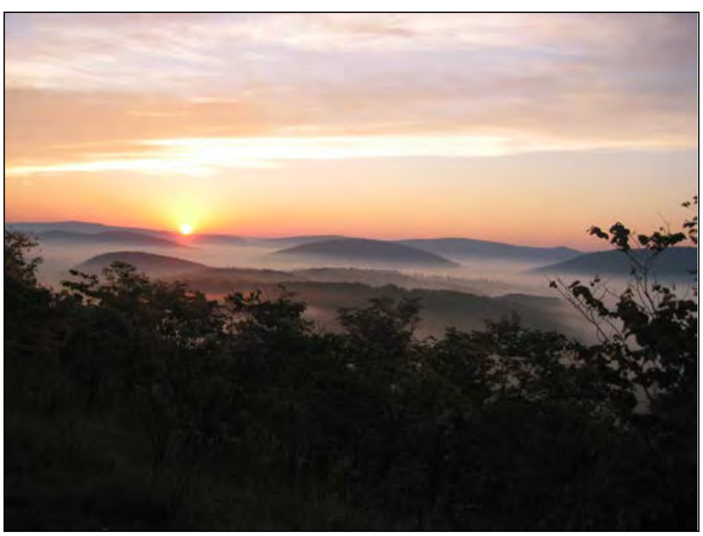


Figure 4. Summertime sunrise in Green Ridge State Forest, Maryland. (Photo by Mark Beals, Maryland Forest Service, 2009)

Hardwood Management

Most loggers produce cut-to-length logs either at the stump or on the landing, although tree-length mill delivery is becoming more popular as hardwood utilization standards improve. Group selection and individual tree selection are the most commonly deployed harvest strategies and natural regeneration from stump sprouting is typically sufficient to regenerate the stand following harvest. Browsing by overly abundant deer populations are problematic, however, for long-term retention of oak regeneration throughout most of Maryland. In addition, invasive species such as Japanese barberry (*Berberis thunbergii* DC), multiflora rose (*Rosa multiflora* Thunb.), Japanese stiltgrass (*Microstegium vimineum* [Trin.] Camus), eastern hay-scented fern (*Dennstaedtia punctilobula* [Michx.] T. Moore), and others often prevent adequate regeneration. Motivated landowners typically will replant with 1-0 bareroot nursery stock protected with a tree tube. Timber stand improvement practices are becoming increasingly familiar as more landowners realize the benefits derived from actively improving stand composition and stocking levels at earlier ages. Most timber stand improvement practices employed in hardwood regions involve reducing stocking levels and utilizing the felled material as firewood whenever practical.

Even in the regions of the Eastern Shore and southern Maryland, where pure stands of loblolly pine are most prevalent, the hardwood acreage still represents 50 percent of the total forest. Because of the dominance of the pine industry, however, hardwood silviculture in these areas tends to also be even-aged and stands of yellow poplar, red maple, sweetgum, and mixed oaks are typically tree-length clearcut. Harvested hardwood stands are either allowed to regenerate naturally or are converted to pine after chemical site preparation.

Pine Management

Pine management is common on the lower Eastern Shore and scattered throughout southern Maryland. Even-aged silviculture is widely practiced but to varying degrees of intensity. Because of consistently reliable markets for both pine sawlogs and pulpwood, management intensity is generally highest on the Eastern Shore. Loblolly plantation development reached a zenith in the 1980s after ramping up in the 1960s from the initial onset of industrial forest management led by several paper manufacturers. Following clearcut harvesting, these plantations were established with the aid of mechanical site preparation to include windrowing, bedding, and either machine- or hand-planting using genetically superior 1-0 bare-root nursery stock grown from local seed sources. Planting densities of trees were typically 720/ac (1,777/ha) with a spacing of 6.0 by 10.0 ft (1.8 by 3.0 m) conducted in late winter to early spring. Drainage ditches were installed on the larger tracts that also harbored more productive soils. Prescribed burning was also used extensively in southern Maryland to reduce residual brush and slash. With the widespread use of helicopter applications of imazapyr, chemical site preparation eventually displaced most of the mechanical site preparation and prescribed burns. Machine planting also continually declined in favor of cost-competitive, highly mobile handcrews.

Figure 5. Variable retention harvest in loblolly pine stand on Maryland's Eastern Shore. (Photo by Jack Perdue, Maryland Forest Service, 2009)

Mechanical thinning of pine stands became an established forest management technique in the 1990s. Thinning enables landowners to produce revenue from pulpwood products while simultaneously improving the growth rate and quality of the residual stand. At a stand age of 18 to 22 years, every fifth row typically is removed entirely and inferior trees are removed from the rest. The residual basal area goals typically result in the harvest of about one-third of the stand density to yield a post-harvest basal area of 70 to 90 ft^2/ac (16 to 21 m^3/ha). A second thinning is often conducted at a stand age of 28 to 30 years and again with a goal of retaining 70 to 90 ft^2 of basal area/ac (16 to 21 m^3/ha). After landowners saw the success from mechanically thinning pine plantations, convincing them to thin overstocked pine stands at even earlier growth stages was not difficult. The popularity of precommercial thinning of pine stands was accelerated when government forestry agencies began offering cost-sharing opportunities to encourage the practice. Today, the Maryland Forest Service supports approximately 1,000 ac (405 ha) of precommercial thinning annually.

Final harvests of loblolly pine occur between age 50 and age 70 (figure 5). Longer stand rotations run the risk of being infected with red heart (*Phellinus pini*). Harvests are clearcuts and tree length production of either sawtimber or pulpwood is standard.

Nursery Operations

Maryland was one of the first States to organize a formal agency dedicated to the restoration, management and protection of forest resources. In 1906, the Maryland Forest Service was established under the leadership of Fred W. Besley, a student and employee of Gifford Pinchot at the U.S. Department of Agriculture (USDA), Forest Service. Besley was the superintendent at USDA Forest Service Tree Nursery at Halsey, NE, the first Federal tree nursery established in the country. Protecting and establishing roadside trees was a high priority in the early years of the Maryland Forest Service, and legislation passed in 1906 to protect and enhance roadside trees also included authorizations to develop a tree seedling nursery. The establishment of the nursery was accomplished in 1914 on the grounds of the Maryland Agricultural College (now the University of Maryland). Over time, and with the legendary work ethic and innovations of Silas Sines, the nursery manager, the nursery expanded and outgrew its space in increasingly crowded College Park (Zumbrun 2006). In 1949, a new nursery was established farther out in the countryside between Washington, DC, and Baltimore, MD. The Buckingham Tree Nursery provided a great leap forward in the sciences of seedling production and established the tree improvement program to develop genetically superior loblolly and white pine (*Pinus strobus* L.) seedlings (Zumbrun 2006). After 45 years of service, Sines retired in 1974, and John Ayton became the second nursery manager.

In 1995, a major highway project displaced the Buckingham Tree Nursery, and a new nursery was established near Preston in Caroline County on Maryland's Eastern Shore. Ayton developed and designed the new nursery and was particularly impressed with the sandy loam soils at the new location and the fact that the 300 ac (121 ha) of land would support irrigation, spaces for seed orchards, and opportunities to rotate crops as needed to maintain soil health and control disease. Ayton retired with 35 years of service 1 year after opening the new nursery, which is befittingly named after him (Zumbrun 2006) (figure 6). At its peak in the 1990s, the John S. Ayton State Tree Nursery produced 7 million seedlings annually. Today, two full-time employees and two part-time employees annually produce 3 million seedlings of 40 to 45 species common to Maryland forests (figures 7 and 8). Also, 25 ac

(10 ha) of seed orchard area are at the nursery providing seed for 15 hardwood species and an additional 12 ac (5 ha) of loblolly pine and white pine seed orchard (figure 9). Another 25 ac (10 ha) of loblolly and pitch pine (*Pinus rigida* Mill.) seed orchards are located offsite on the lower Eastern Shore but are not currently used for seed collection. The balance of seed is either collected by staff or volunteers or purchased.

Bareroot seedlings are the only products offered for sale at the Ayton State Tree Nursery. Pricing is designed to remain "at cost" and the goal is to keep reforestation costs low to lessen financial barriers to planting trees. Containerized or ball and burlapped stock is available through the large and diverse commercial nursery industry found throughout Maryland.

Seedlings are machine dug from nursery beds in late winter and manually graded, counted, root-dipped, and packaged in units of 25, 50, 100, or 1,000 seedlings per bundle, depending on species. These bundles are stored in industrial coolers until they are shipped for planting a few weeks later in early spring. Orders are facilitated by a secure Web site, over the phone, or through the assistance of a Maryland Forest Service forester. Smaller orders are shipped directly to customers using UPS (United Parcel Service). Refrigerated tractor-trailers are used to transport seedlings in bulk to temporary walk-in coolers throughout the State, where Forest Service foresters pick up seedlings required for the plantings they are coordinating on behalf of private landowners.

The Ayton State Tree Nursery is the only nursery in Maryland producing bareroot seedlings. By law, seedlings may be sold only for conservation purposes, and trees grown from seedlings produced at the Ayton State Tree Nursery may not be sold in the future with intact root systems.

Tree Planting Programs

Maryland landowners are offered numerous forms of cost-share to plant seedlings (figure 10). The State-administered Woodland Incentive Program (WIP) provides 65 percent reimbursement for all tree planting costs, including site preparation, seedlings, planting labor, and up to 400 tree tubes/ac (988/ha). Federal cost-share is offered by the USDA, Natural Resources Conservation Service (NRCS) through the Environmental Quality Incentive Program (EQIP), which provides 75 percent of anticipated costs for a similar range of planting activities. Landowners can simultaneously subscribe to both programs to receive a maximum 90-percent reimbursement. Although both programs provide assistance

Figure 6. Entrance sign to the John S. Ayton State Forest Tree Nursery at its grand opening. (Photo by Richard Garrett, Maryland Forest Service, 2004)

Figure 7. Aerial view of seedling beds at Maryland's John S. Ayton State Forest Tree Nursery. (Photo by Richard Garrett, Maryland Forest Service, 2009)

Figure 8. One employee constitutes the entirety of the weeding crew at Maryland's State tree nursery. Soil fumigants are used in small portions of the nursery, but most weed control is accomplished by diligence with cultural techniques. (Photo by Richard Garrett, Maryland Forest Service, 2009)

Figure 9. Hazelnut seed orchard during early development. (Photo by Richard Garrett, Maryland Forest Service, 2009)

with supplemental reforestation practices, such as controlling grasses or reinforcement planting, neither program provides support for ongoing maintenance of tree tube replacement or removal.

In the past decade, planting sites were roughly equally allocated between reforestation and afforestation. More recently, however, reforestation acreages have been steadily declining and will likely continue to do so. Nearly all corporate timber lands in Maryland were divested between 2000 and 2010, and the many new owners are not harvesting as intensively, which results in fewer acres to reforest. Much of these former corporate timber lands are now encumbered by conservation easements that require all future owners to ascribe to forest certification standards. These standards limit timber harvests to no more than 40.0 ac (16.2 ha) maximum, and most are much smaller. Natural regeneration is a preferred low-cost regeneration technique on small harvest sites. Afforestation has also declined in recent years because of the waning popularity of riparian buffer establishment programs such as the Conservation Reserve Program and the Conservation Reserve Enhancement Program. In 2004, the nursery provided all seedlings for tree plantings on 4,033 ac (1,632 ha) of combined reforestation and afforestation efforts, and, by 2014, this total had dropped to 1,134 ac (459 ha). The nursery has adapted to these declining seedling markets by increasing direct marketing to individual landowners interested in planting trees not associated with timber harvesting or riparian buffer establishment. Likewise, the Maryland nursery provides seedlings to forestry agencies of other States that do not have seedling nurseries.

Maryland hosts or participates in several incentive programs designed to encourage tree planting. The WIP is the hallmark cost-share program for most traditional, rural forest improvement work. Eligibility standards for this program require that

Figure 10. Planting seedlings with tree tubes. (Photo by Richard Garrett, Maryland Forest Service, 2003)

the forest shall be capable of producing a commercial product at some point in the future, but no stipulation requires the landowner to harvest. The WIP supports planting of bareroot seedlings on more than 1,000 ac (405 ha) annually and chemical site preparation on 900 ac (364 ha) annually. The NRCS EQIP cost-share also supports planting and site preparation efforts but to a far lesser extent because of the comparative complexities of enrollment application forms. The Glatfelter Pulpwood Company (Spring Grove, PA) provides an annual stipend to the Maryland Forest Service to offset seedling costs on a first-come, first-serve basis to landowners in regions where the company procures pulpwood.

In addition, the Maryland Forest Service offers several other programs designed to encourage planting of larger trees in areas more closely associated with built environments or urban settings. For example, the "Lawn to Woodland" program offers free tree planting of seedlings on lawn areas up to 1.0 ac (0.4 ha); the "Marylanders Plant Trees" program offers a $25 coupon through participating retail nurseries for purchasing container stock and then registering the location of the planting on a State Web site; the "Tree-mendous Maryland" program coordinates the planting of balled-and-burlapped stock in public spaces in partnership with volunteers; and the "Healthy Forests, Healthy Waters" program is a grant-funded effort intended to plant seedlings in high-priority watersheds in locations that directly improve water quality.

Future Issues

Like many other forested areas in the country, Maryland is experiencing a decline in forested acres. The most recent survey indicates that, between the years 1998 to 2007, Maryland's net decline in forest cover was approximately 3,000 ac (1,214 ha) per year (Lister et al. 2011). Approximately 7,000 ac (2,833 ha) of forest are lost each year to land development while 4,000 ac (1,619 ha) of open land are converted to forest cover, mainly from former agricultural land (Lister et al. 2011). It is not surprising that land development is expected to continue and, in future years, this development will likely gravitate away from the increasingly valuable agricultural lands and more toward the comparatively less expensive forested lands. In addition, forest gains from agricultural reversion to forest will likely diminish significantly. The combined result will be an increasing rate of forest loss.

Challenges that lie ahead for forestry and forest management are rooted in demographic shifts. In 1975, small forest ownerships of less than 10 ac (4 ha) were held by 52,690 landowners (Kingsley and Birch 1980, Powell and Kingsley

1980). Today, the number of small ownerships has increased to 129,480 landowners (Lister et al. 2011). The implications of this increase are many, especially when considering that overall forest acreage is declining, which means that larger tracts capable of supporting management activities are diminishing. The continuing decrease in tract sizes, which affects the capacity to carry out meaningful silvicultural activities, is fueled in large part by the increased mobility of our population. Land transfers are frequently precipitous catalysts for subdividing properties into smaller units for resale. Also, most forest owners in Maryland are 60 years old or older, and they often subdivide their lands before transferring to family members. Younger land owners and those who inherit land often value forests for their nonfinancial amenities and less so for their utilitarian market values, and these landowners tend to harvest less often and are less aware of the need for active management to maintain forest health. Smaller tracts are less efficient for timber harvesting and, although the quality of timber products on a small tract may be high, the overall volume is not sufficient to recoup the costs of harvesting. Therefore, as more forested properties are subdivided and shift into the "small tract" category, more of the forest is no longer economically or socially eligible for continued active management.

Conclusions

The diversity of Maryland's climate, physiography, and cultures all affect the past, present, and future condition of the State's forested landscapes. For four centuries, the forests of Maryland have provided needed resources for a wide variety of products and purposes, and only during the past century have people deliberately invested in stewardship of this resource. The results are mixed: evidence of positive effects include the fact that our forests are five times as bountiful as they were 100 years ago, yet most recent data demonstrate forested acreage is declining. More challenging is the fact that average tract sizes are decreasing, which is a deepening concern because owners of smaller properties are less interested in managing the small portions of the forest they own for forest products, or to invest in protecting these forests against threats to forest health.

Address correspondence to—

Daniel Rider, Forest Stewardship and Utilization Program Manager, Maryland Department of Natural Resources Forest Service, 580 Taylor Avenue, E-1, Annapolis, MD 21401; e-mail: daniel.rider@maryland.gov; phone: 410–260–8583.

Acknowledgments

The author acknowledges the hard work and successes of current and former Maryland Forest Service employees, and especially Richard Garrett, manager of the John S. Ayton State Tree Nursery.

REFERENCES

Besley, F.W. 1916. The forests of Maryland. Baltimore: Maryland State Board of Foresters. 152 p.

Besley, F.W.; Dorrance, D.G. 1919. The wood-using industries of Maryland. Baltimore: Maryland State Board of Foresters. 122 p.

Frieswyk, T.S. 2001. Forest Statistics for Maryland: 1986 and 1999. Res. Bull. NE-154. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 164 p.

Kingsley, N.P.; Birch, T.W. 1980. The forest-land owners of Maryland. Res. Bull. NE-63. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeast Forest Experiment Station. 78 p.

Lister, T.W.; Perdue, J.L.; Barnett, C.J.; Butler, B.J.; Crocker, S.J.; Domke, G.M.; Griffith, D.; Hatfield, M.A.; Kurtz, C.M.; Lister, A.J.; Morin, R.S.; Moser, W.K.; Nelson, M.D.; Perry, C.H.; Piva, R.J.; Riemann, R.; Widmann, R.; Woodall, C.W. 2011. Maryland's forests 2008. Res. Bull. NRS-58. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 60 p.

Middleton, A.P. 1953. Tobacco Coast: a maritime history of Chesapeake Bay in the colonial era. Originally: The Mariner's Museum, Newport News, VA. Reprinted 1984. Baltimore: Johns Hopkins University Press. 508 p.

Powell, D.S.; Kingsley, N.P. 1980. The forest resources of Maryland. Res. Bull. NE-61. Broomall, PA. U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 103 p.

Rider, D.R. 2006. A 100-year comparison of Maryland's forest products industry. Annapolis: Maryland Department of Natural Resources, Forest Service. 2 p.

Rider, D.R. 2012. Maryland's forest industry: a pillar of our economy and quality of life. Annapolis: Maryland Department of Natural Resources, Forest Service. 16 p.

Zumbrun, F. 2006. Father of Maryland forestry brought tree nursery science to Maryland. http://www.dnr.state.md.us/centennial/TreeNurseryScience_History.asp. (April 2015).

New Mexico Locust (*Robinia neomexicana*) Establishment on Mining Overburden

Jon Hawthorne, April Ulery, John Harrington, John G. Mexal, Dawn M. VanLeeuwen, and Anne Wagner

Environmental Manager, CLP Resources, Sparks, NV; Professor, Department of Plant and Environmental Sciences, New Mexico State University, Las Cruces, NM; Professor (deceased), Department of Plant and Environmental Sciences, New Mexico State University, Mora, NM; Professor Emeritus, Department of Plant and Environmental Sciences, New Mexico State University, Las Cruces, NM; Professor, Department of Economics, Applied Statistics, and International Business/Agricultural Biometric Service, New Mexico State University, Las Cruces, NM; Team Manager, Chevron Energy Technology Company, San Ramon, CA

Abstract

Mining presents challenges in revegetation efforts, particularly on exposed overburden. New Mexico locust (*Robinia neomexicana* Gray) has long been considered a good candidate for mine reclamation in the Southwestern United States, although little published data exists. Scarified New Mexico locust seeds were hydroseeded onto mining overburden screened to < 15 cm (6 in). Emergence was evaluated during the latter part of one field season using a blocked, split-plot design with the whole-plot factor of three mulch treatments (0, 1,121, or 2,242 kg/ha [0, 1,001, or 2,002 lb/ac]) and the split-plot factor of three composted, biosolid treatments (0.0, 112.5, or 225.0 Mg/ha [0.0, 50.2, or 100.4 ton/ac]). No differences were evident in emergence among mulch and biosolid treatment combinations. A higher number of emergents were observed in locations shaded by rocks than in open areas, and a higher percentage of seedlings that emerged from the protected areas were observed to survive than those that emerged in open areas. Future studies are required to confirm whether rock cover is beneficial to seed emergence and survival whereas organic amendments, incorporated or surface applied, had no effect at the rates applied.

Introduction

Mine reclamation, for cases in which little topsoil exists, may require amending rocky overburden with organic matter. The high rock fragment content has low water-holding capacity and fertility and can inhibit plant root volume (Munn et al. 1987). Rocky surface conditions can reduce erosion but may also reduce seed-to-soil contact (Redente et al. 1982), a problem when direct seeding.

New Mexico locust (*Robinia neomexicana* Gray) is a legume (Fabaceae) with several qualities that make it a good candidate for revegetation in disturbed areas: it fixes nitrogen, stabilizes soil, grows quickly, and, once established, is drought tolerant (Kuhns 1998, Thornburg 1982, USDA NRCS 2012, Vogel 1987). Transplanted New Mexico locust showed a fair survival rate after 6 years in a variety of New Mexico overburden materials (Dreesen 2000). Information regarding New Mexico locust germination in the field, however, is limited almost exclusively to laboratory (Khadduri et al. 2003) and greenhouse (Lin et al. 1996) experiments.

New Mexico locust is a rhizomatous, perennial, woody shrub or small tree (Wooton 1913). It is native to the American Southwest and Mexico, at an elevation range of 1,370 to 2,740 m (4,500 to 9,000 ft) in New Mexico (Carter 1997) but has been documented as high as 2,950 m (9,700 ft) elsewhere (Niering and Lowe 1984). It is found in understory and open areas (Martin and Hutchins 1984) and along montane riparian zones (Cudworth and Koprowski 2011, Danzer et al. 2001, Freeman and Dick-Peddie 1970, Martin 2007, Medina and Martin 1988, Skartvedt 2000, Toolin et al. 1979). Ease in establishment from seed has been categorized as “medium” and spread from seed as “good” (Plummer 1977). After it is established, New Mexico locust grows quickly (USDA NRCS 2012).

New Mexico locust is adapted to a variety of soil textures from sandy to clayey (Thornburg 1982, Vincent 1996, USDA NRCS 2012) and is often found on rocky sites (Buegge 2001, Darrow 1950, Frey and Schwenke 2012, Wooton 1913). Soil fertility requirement is “low” and calcium carbonate tolerance is “high” (USDA NRCS 2012). New Mexico locust forms a symbiotic association with *Rhizobium* (Kuhns 1998), and the nitrogen-fixing capacity in monoculture is up to 95 kg/ha/yr (85 lb/ac/yr) (USDA NRCS 2012). As a consequence, it is adaptable to a wide range of chemical and physical soil conditions and is tolerant of nutrient-poor soils, making it a strong competitor when establishing and growing in a variety of edaphic conditions.

Often plants growing on harsh (droughty, full sun) sites are found under inanimate objects such as tree stumps (Coop and Schoettle 2009) or rocks (Parker 1987). Before the term "nurse rock" was first used (Parker 1987), Kay (1978) noted that surface rocks offered several benefits to plant establishment and Conn and Snyder-Conn (1981) reported that cracks in rocks provided favorable germination conditions. Nurse rocks benefit plants across environments ranging from warm desert (Masrahi et al. 2012) to cool, high-elevation areas (Resler et al. 2005).

Although New Mexico locust is tolerant of poor soils, amendments are suggested to benefit revegetation, including organic matter, mulch, and supplemental irrigation. Organic matter in the form of composted municipal biosolids is often applied at rates of 56 to 224 Mg/ha (25 to 100 ton/ac) or more to hard rock mine sites (EPA 2007). Soils with incorporated composted biosolids have been reported to hold moisture longer than unamended soils (Risse et al. 2009) and organic compounds within compost may facilitate long-term soil aggregate stability (Piccolo and Mbagwu 1990). Composts typically have low C:N ratios for nitrogen mineralization (Harmsen and Kolenbrander 1965) providing slow, long-term beneficial release of nitrogen and other nutrients (Granberry et al. 2001, Maynard 2000).

Composted biosolids are available from wastewater treatment plants and often contain high-nutrient content, but may also be high in salts or heavy metals. When composts are applied on slopes, inorganic forms of nitrogen such as nitrate and ammonium are more likely than organic forms to runoff (Risse et al. 2009). Nitrogen additions not lost as runoff can persist for decades after application in revegetated areas (Wick et al. 2009). Composted biosolids have demonstrated no effect on seed germination of some species (Ligneau and Watt 1995), but reduced germination (Ayuso et al. 1996, Ozores-Hampton et al. 1999) or delayed germination (Wollan et al. 1978) in other species.

Another amendment that is commonly recommended for revegetation using direct seeding is mulch. On the ground, mulch protects seeds (Barnett et al. 1967), decreases soil moisture evaporation, and reduces soil erosion. Mulch should be applied after seeding to increase seed-to-soil contact (Ferns et al. 1996, Parrish and Anderson 1994, Wood and Buchanan 2000), although excess mulch atop seed can slow or prevent seed germination due to cooling or acting as a physical barrier (Lyle 1987).

Data are limited regarding germination and emergence of New Mexico locust *in situ*. The objective of this study was to determine the effects of surface rock cover, incorporated composted biosolid, and mulch treatments on the emergence and survival of seeded New Mexico locust in overburden material.

Materials and Methods

The study was conducted at New Mexico State University's John T. Harrington Forestry Research Center at Mora, NM (formerly the Mora Research Center). Climate in this region is semiarid, with precipitation occurring bimodally as monsoonal rain from July to September and moderate to heavy snow from November to April. Temperature fluctuates both seasonally and diurnally. Mean daily temperature fluctuation is 18 °C (32 °F), and mean frost-free (greater than 0 °C or 32 °F) days are approximately 130 (Western Regional Climate Center data—http://www.wrcc.dri.edu).

Seed

New Mexico locust seedpods were collected from the John Harrington Forestry Research Center in August 2009. The pods were air dried for approximately 3 weeks, and seeds were separated from pods by hand maceration. Debris was removed via threshing, followed by use of a seed blower. Seeds were stored in plastic freezer bags at approximately 3 °C (37 °F) until used.

Seeds were separated with a 3.00-mm (0.12-in) seed sieve (Humboldt Mfg. Co., Norridge, IL) into large (38,818 seeds/kg [17,605 seeds/lb]) and small (57,750 seeds/kg [26,190 seeds/lb]) sizes. Only large seeds were used for this trial. Seeds (16,200) were scarified by dropping them into boiling tapwater. The heat was immediately shut off, the hot water poured off and replaced with room temperature (~22 °C [72 °F]) tapwater, and the seeds then allowed to soak for 24 hr. The seeds were then removed from the water and air dried for 2 hr to approximately 50 percent moisture loss (based on germination studies described in Mexal et al., 2015). Moisture content was determined by weighing batches of seeds in 15-min intervals, from full hydration to 50 percent water loss. Seed, *Rhizobium* inoculant (17.90 g [0.63 oz]) (Plant Probiotics, Indianapolis, IN) and 10.00 g (0.35 oz) guar gum (Source Naturals, Santa Cruz, CA) were placed in a container, sprayed with sufficient tapwater to fully moisten the constituents, and hand shaken for 1 minute. The scarified seeds were counted into individual lots of 300, placed in plastic bags, and stored at 3 °C (37 °F) over night.

Overburden Material

Overburden material was sourced from a hardrock mine located in New Mexico's Taos Range within the Sangre de Cristo Mountains, part of the Southern Rocky Mountain physiographic province. Elevation of the mine site ranges from 2,300 to 3,300 m (7,500 to 10,800 ft). The overburden material is composed of highly weathered, intrusive, igneous rock. Soil texture within the overburden is sandy loam to loamy sand ranging from 66 to 77 percent sand, 18 to 27 percent silt, and 4 to 12 percent clay (Tahboub 2001). Rock fragment is 48 to 77 percent (Tahboub 2001), typical of mine soils and overburden (Ashby et al. 1984). Saturated paste pH of the overburden is generally neutral to slightly alkaline (6.8 to 7.7), total dissolved solids are 410 mg/L (410 ppm), electrical conductivity and sodium adsorption ratio are also low (Shaw et al. 2002, Tahboub 2001), indicating that the overburden is neither saline nor sodic. In addition, organic matter content ranges from 0.3 to 0.7 percent (Tahboub 2001). The overburden contains high amounts of calcium carbonate, indicated by strong effervescence of the material when reacted with 1 percent hydrochloric acid (USDA NRCS 2011).

Treatments

Eighteen 2.4 by 2.4 m (8.0 by 8.0 ft) square frames were constructed of lumber. Sheets of flattened expanded metal carbon steel (#13, Reliance Steel Company Albuquerque, NM) were cut and placed on the frames to support the overburden. Two 3.8 by 14.0 cm (2.0 by 6.0 in) dividers were attached to the frames (over the expanded flattened mesh metal screen) to further subdivide them into three 236.2 by 78.7 cm (93.0 by 31.0 in; 1.85 m^2 [19.10 ft^2]) "subframe" units (figure 1). Water-permeable weed barrier (Dewitt Pro 5, Greenhouse Supply, Albuquerque, NM) was cut and placed on the bottom of each individual subframe and stapled to all sides.

The 18 frames were divided into 3 clusters (blocks) of 6. Within each block, 2 frames were randomly assigned to receive zero, medium (1,121 kg/ha [1,001 lb/ac]), or high (2,242 kg/ha [2,002 lb/ac]) mulch applications for a total of 6 replicates per whole-plot treatment (mulch) level. Within each frame,

Figure 1. Single 2.4 by 2.4 m (8.0 by 8.0 ft) square frame divided into three subframes. Overburden has been added above metal mesh screen and weed barrier (not visible) in far right subframe. (Photo by Jon Hawthorne, 2012)

subframes (subplots) were randomly assigned to incorporation of zero, medium (112.5 Mg/ha [50.2 ton/ac]), or high (225.0 Mg/ha [100.4 ton/ac]) biosolid treatment. The medium biosolid rate was suggested for testing by Chevron Mining, Inc., and we included zero and high rates for comparison.

Each subframe was filled with overburden, screened to remove rocks larger than 15 cm (6 in), to a depth of 7 cm (3 in). Screened (< 1.3 cm [0.5 in]) composted biosolids were purchased from the City of Santa Fe, NM's wastewater treatment plant. Biosolids were analyzed by the city and reported to be slightly acidic, low in salts, and contain 52 percent organic matter based on loss-on-ignition during combustion and 25 percent moisture. Offered as "compost," the product is a mixture of wastewater-derived biosolids and green waste composed of pulverized wood, brush trimmings, and horse bedding (http://www.santafenm.gov/index.aspx?NID=1313). The composting process significantly reduces pathogens in the biosolids, which are consequently considered "Class A" and publicly available. Biosolids were weighed separately for each subframe, placed on top of the overburden, and manually incorporated into the overburden with a heavy rake.

Each subframe was seeded in early August by adding 300 scarified seeds and 5.00 L (1.32 gal) of tapwater to an 18.9 L (5.0 gal) bucket, then placing a submersible pump (Little Giant Pump Company Model No. 5-MSP) in the bottom center of the bucket to simulate hydroseeding. The screen on the bottom of the pump was removed to allow for passage of seeds into the pump, and screws were placed in holes at the pump's four corners to raise it approximately 5.0 mm (~0.2 in) above the bottom of the bucket. The bucket was gently agitated until most of the seeds had been discharged (approximately 10 sec). Any seeds remaining in the bucket (usually < 5 percent) were applied to the subframe by adding enough water to the bottom of the bucket (without pump) and hand applying the seed/water combination onto the center of the subframe. A cardboard barrier was positioned to keep seeds within the confines of the subframe during seeding.

Mulch treatments were applied the day following seeding. Mulch, composed of tree waste processed twice through a wood chipper, was acquired from Las Vegas, NM. Air dry mulch was weighed out separately for each subframe, applied by hand, and raked across the overburden to distribute evenly after seeding. After mulching, each frame was covered with wildlife netting (1.90 cm [0.75 in] mesh; Greenscapes Home and Garden Products Inc., Calhoun, GA) to prevent predation.

Irrigation was applied via garden hose and sprayer to the frames at an initial rate of 1.20 L (0.32 gal) or 0.65 mm (0.03 in) per subframe 6 and 8 days after seeding to wet the surface. From days 10 through 18, each subframe was irrigated daily to the point at which irrigation water pooled on the overburden surface and drainage through the weed barrier was evident. The increased irrigation met reference evapotranspiration (ET) demands (NMSU Climate Center 2012). Using the same approach, frames were watered twice daily from days 19 through 27, and once daily between days 28 and 47.

Data Collection and Statistical Analysis

Emergence was counted and recorded every 3 days through day 33 and weekly thereafter through day 47. Poultry leg bands (Kuhl Corp., Flemington, NJ) were placed on new emergents to track emergence by day (Mexal and Fisher 1987). A different color was used for each day (figure 2). Emergence was tallied by day for each frame (mulch treatment) and subframe (biosolid treatment) for 47 days after seeding. Days to 50 percent final emergence (referred to here as "E_{50}" similar to the use of 50 percent germination or "G_{50}" in lab studies) were computed by comparing seedling emergence with total emergence over time. Proximity to rocks was recorded for each emergent. Emergents were considered "protected" if they were directly below a rock (shaded by overhead sun) or "open" if not below a rock. Survival was defined as emergents still living at 47 days after seeding.

Data in the randomized blocked split-plot experimental design were analyzed to assess the effects of mulch (the whole-plot factor) and biosolid (the subplot factor) treatments on emergence of New Mexico locust. In addition to fixed effects for mulch, biosolids, and their interaction, the model included random effects for block and whole-plot experimental units. Total emergence and survival at 47 days were analyzed using SAS version 9.3 PROC GLIMMIX software (SAS Institute Inc. 2011) to fit a generalized linear mixed model that explicitly recognized a binomial response distribution, used the logit link, and was fitted using Laplace integral approximation. Data-scale inverse linked estimates were reported. The E_{50} was analyzed using a model assuming normality with SAS version 9.3 PROC MIXED software. Emergence and survival in protected versus open areas were summarized descriptively. Significance was defined at $p \leq 0.05$.

Figure 2. New Mexico locust seedlings emerging from under rocks in overburden. Different colored bands indicate different days of emergence as observed in the field. Wildlife netting visible is ~10 cm (4 in) above the seedlings. (Photo by Jon Hawthorne, 2012)

Results

Emergence ranged from 6.1 to 8.6 percent, with no significant differences among treatment combinations (table 1). Emergence began on day 15, 5 days after irrigation was increased to meet reference ET demands (figure 3). A rainfall event of 22.30 mm (0.88 in) on day 25 was followed by marked increase in new emergence on days 27 and 30. Emergence peaked on day 30, and no additional emergence occurred by day 47. E_{50} was significantly higher in plots with zero biosolids than in plots with the high biosolid treatment (30.33 ± 0.42 days versus 29.00 ± 0.42; $p = 0.0114$), but did not differ from plots with the medium biosolid rate (29.50 ± 0.42 days). Survival was 83.1 percent (range = 75.0 to 87.5 percent) and did not differ among treatments (data not shown).

In every subplot, the number of seeds emerging in rock-shaded areas was higher than the number emerged in open areas. Among treatment groups, 0.3 to 1.6 percent of seeds emerged in open areas while 5.4 to 7.7 percent of seeds emerged in shaded areas; the proportion of emergents occurring in shaded areas ranged from 77.8 to 94.6 percent. Considerable differences existed between survival of emergents that were noted in open areas and those that emerged protected underneath rocks (0 to 12.5 percent versus 92.4 to 95.1 percent, respectively) (figure 4).

Table 1. Emergence percent estimates using generalized linear mixed model fitted with Laplace integral approximation (SE).

Mulch (kg/ha)	Biosolid (Mg/ha)			Mean (%)
	0	112.5	225	
0	7.95 (0.79)	8.45 (0.82)	8.61 (0.83)	**8.34**
1,121	6.96 (0.73)	7.24 (0.75)	7.35 (0.75)	**7.18**
2,242	6.99 (0.73)	6.11 (0.67)	7.60 (0.77)	**6.90**
Mean (%)	**7.30**	**7.27**	**7.85**	**7.47**

p-values: Biosolid main effect ($p = 0.4082$), mulch main effect ($p = 0.1014$), and interaction ($p = 0.6895$).

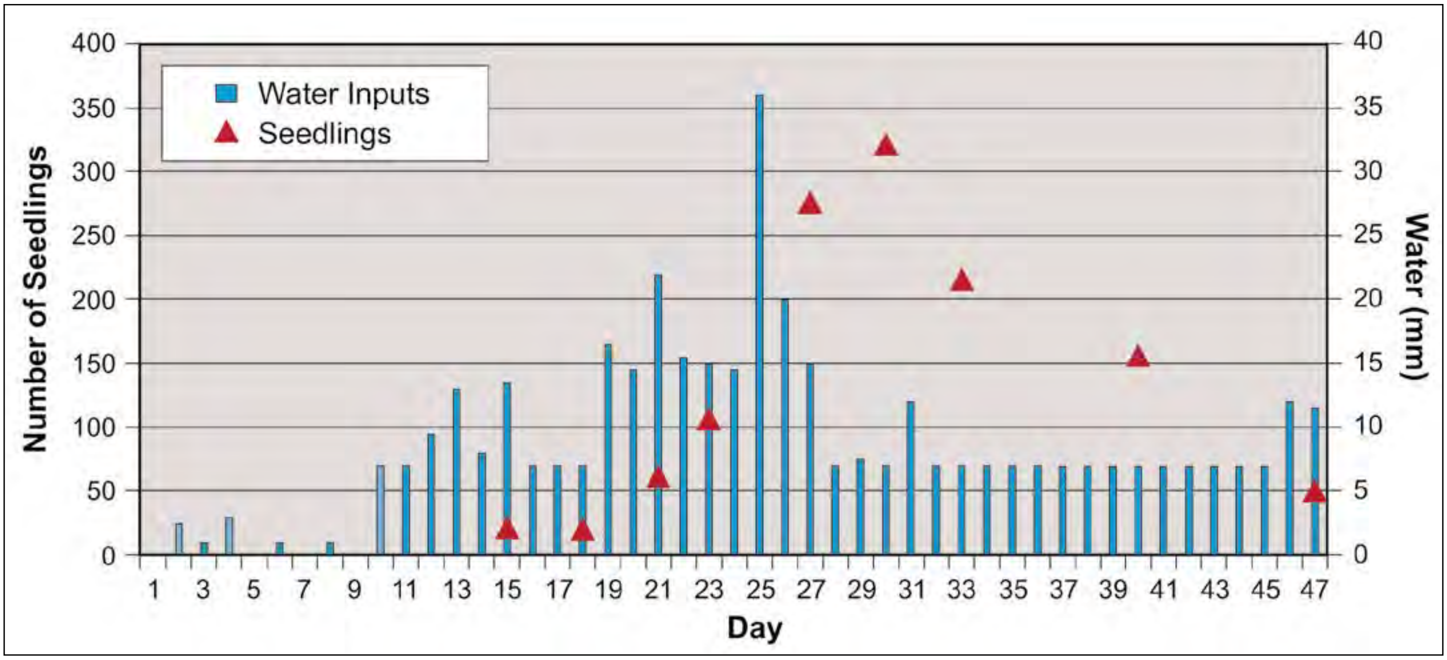


Figure 3. Number of newly emerged New Mexico locust seedlings on days after seeding and daily water inputs (rainfall plus irrigation).

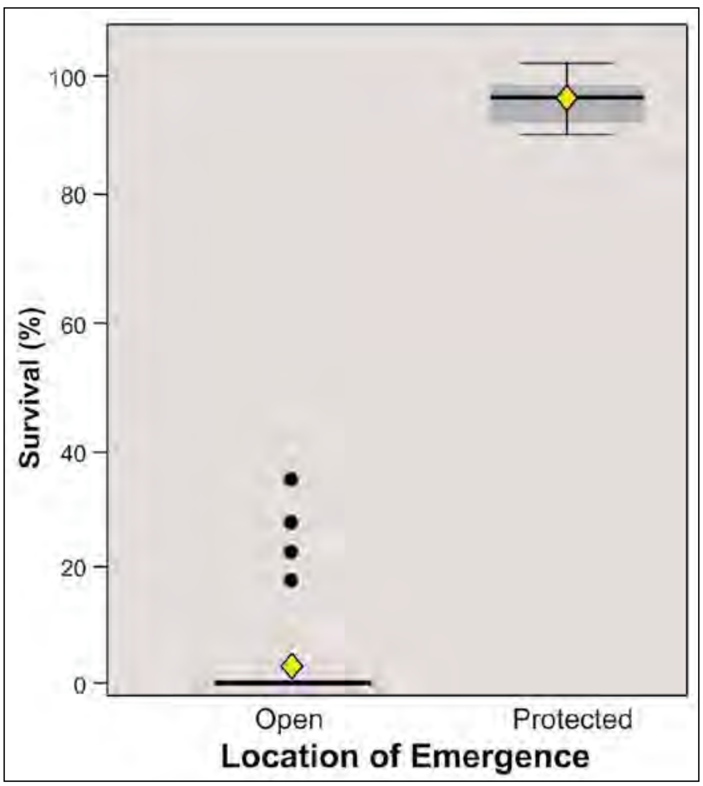


Figure 4. Box and whisker plot for survival at the end of the 47-day study (as a percent of total seed broadcast in each subframe) of New Mexico locust seedlings in "open" space (between rocks) or "protected" by rocks. Biosolids and mulch treatments were combined. The mean is represented by a diamond. Filled circles are outliers.

Discussion

Emergence of New Mexico locust in this study was similar to that of hand broadcast black locust after one growing season (7 to 10 percent) (Vogel and Berg 1973). Direct seeding, either for reforestation or restoration, generally results in low germination and seedling establishment. Direct seeding success is inherently variable, depending on site quality, seed quality, and environmental factors, including predation. Hence, seeding rates are often high. Little et al. (1958) found that direct seeding of pitch pine (*Pinus rigida* Mill.) in New Jersey resulted in 2.5 to 13 percent emergence, depending on site quality and seed size. Doust et al. (2006) found small-seeded species (similar to locust seed size) averaged 1 to 4 percent emergence after 2 months when broadcast onto cultivated soil. Seeding New Mexico locust at the recommended rate of 1.50 million seeds/ha (0.61 million seeds/ac) could result in more than 15,000 seedlings/ha (6,073 seedlings/ac) or 1.00 seedling/m^2 (0.84 seedlings/yd^2) with just 1 percent germination and survival. Thus, 7 to 10 percent emergence in the first growing season should lead to successful establishment on restoration sites.

Seeds in our study were scarified then dried to 50 percent moisture content to facilitate seeding, as hydroseeding can reportedly crush hydrated, scarified New Mexico locust seed (Hine et al. 1997). Drying the seed to 50 percent moisture content obviated this issue but may have reimposed dormancy or seeds may have failed to emerge for other reasons. Nevertheless, little emergence occurred in the study until at least 7.5 mm (0.3 in) of water was applied as irrigation, enough to provide seeds on the surface with sufficient moisture to germinate and emerge. Rainfall events in subsequent days were generally followed by increased emergence. The effect of moisture on emergence indicates that New Mexico locust should be seeded before seasonal monsoons occur. Olson and Karrfalt (2008) recommend seeding "locust" between March and May. This recommendation is logical if no irrigation is planned, and emergence is reliant on snowmelt or incipient soil moisture.

Biosolids and Mulch Effects on Emergence

The nonsignificant differences among biosolid and mulch treatments on total emergence of New Mexico locust were unexpected. Mulch is recommended to help retain surface moisture, but the rates applied in this study, which were based on rates that could be applied via hydromulching and evaluated previously in a similar mine revegetation study (Golder Associates 2004), appeared to have no effect. Biosolids incorporated in the overburden consisted of only 52 percent organic matter; while biosolids can be up to 70 percent organic material, most treated biosolids have surprisingly high amounts of inorganic material (Epstein 2002). Thus any anticipated benefit may be reduced by the inorganic components of biosolids.

While biosolids did not improve seed germination, it did reduce E_{50} time, which was in contrast to other studies (Lin et al. 1996, Wollan et al. 1978) and may have been due to increased soil-to-seed contact or improved water-holding capacity.

This study suggested little benefit from application of either mulch or biosolids. Although mulch is often available free of charge, it can be expensive to transport and apply. Composted biosolids can be costly to purchase and to incorporate on site. The biosolids used in this study, purchased from one of the nearest sources to the mine, cost \$15.76/m^3 (\$11.50/yd^3).

Effects of Rocks on Seedling Emergence and Survival

Although rock fragments are often viewed as having a negative effect on seeding and moisture retention in soil (Carlucci et al. 2011, Haussmann et al. 2010, Kleier and Lambrinos 2005), we noted more seedling emergence in the proximity of rocks than in open space. Rocks may have facilitated germination and emergence by providing protected microsites or they may have served as catchment zones, resulting in higher seed concentrations. Nevertheless, seedling survival at 47 days was higher in the proximity of rocks compared with open areas; similar to other studies (Maestre et al. 2003, Peters et al. 2008, Resler et al. 2005). However, seedling emergence in protected versus open sites was not a factor in this study design. Future studies specifically designed to assess the effect of protected versus open sites are needed to understand the benefits of surface rocks.

These beneficial "nurse rocks" have also been referred to as safe sites (Fowler 1988) and microsites (Kleier and Rundel 2004). Rocks may have benefitted New Mexico locust emergence by serving as a seed trap (Haussmann et al. 2010) and by preventing desiccation of seeds and seedlings by protecting them from sun and wind, decreasing soil temperature, and increasing moisture content (Nobel et al. 1992). The overburden hardened noticeably after wetting and drying cycles and may have prevented seed radicle entry and establishment (Campbell and Swain 1973). Another benefit from rocks is that they provide leverage against which the seeds can push, allowing the radicle to enter the surface instead of pushing the seed over and raising the radicle (Dowling et al. 1971).

Conclusions

Because no differences in emergence or survival existed between any of the treatment groups, neither composted biosolids nor wood fiber mulch are warranted at the rates tested. Rainfall coupled with supplemental irrigation was required for seedling establishment.

In this study, rocks larger than 15 cm (6 in) were removed from the overburden. Nevertheless, surface rocks may provide protected sites for New Mexico locust to germinate, emerge, and become established. We observed more seedlings under rocks compared with open areas suggesting that surface rocks provide beneficial habitat for seedling establishment. Leaving rocks in place may be key to mine reclamation and revegetation, particularly in a semiarid region.

Address correspondence to—

April Ulery, Professor, Department of Plant and Environmental Sciences, New Mexico State University, POB 30003, MSC 3Q, Las Cruces, NM 88003; e-mail: aulery@nmsu.edu.

Acknowledgments

This research was partially funded by Chevron Mining, Inc., and the New Mexico Agricultural Experiment Station. Neither funding source had any role in the study design, data collection, analysis and interpretation of data, and report writing or in the decision to submit the article for publication.

REFERENCES

Ashby, W.C.; Vogel, W.G.; Kolar, C.A.; Philo, G.R. 1984. Productivity of stony soils on strip mines. In: Box, J.E., Jr., chair. Erosion and productivity of soils containing rock fragments. SSSA special publication number 13. Madison, WI: Soil Science Society of America: 31–44. Chapter 4.

Ayuso, M.; Hernandez, T.; Garcia, C.; Pascual, J. 1996. Stimulation of barley growth and nutrient absorption by humic substances originating from various organic materials. Bioresource Technology. 57(3): 251–257.

Barnett, A.P.; Diseker, E.G.; Richardson, E.C. 1967. Evaluation of mulching methods for erosion control on newly prepared and seeded highway backslopes. Agronomy Journal. 59(1): 83–85.

Buegge, J.J. 2001. Flora of the Santa Teresa Mountains in Graham County, Arizona. Journal of Arizona-Nevada Academy of Science. 33(2): 132–149.

Campbell, M.H.; Swain, F.G. 1973. Effect of strength, tilth and heterogeneity of the soil surface on radicle-entry of surface-sown seeds. Journal of British Grass Society. 28(1): 41–50.

Carlucci, M.B.; Duarte, L.D.S; Pillar, V.D. 2011. Nurse rocks influence forest expansion over native grassland in southern Brazil. Journal of Vegetation Science. 22(1): 111–119.

Carter, J.L. 1997. Trees and shrubs of New Mexico. Boulder, CO: Mimbres Publishing. 534 p.

Conn, J.S.; Snyder-Conn, E.K. 1981. The relationship of the rock outcrop microhabitat to germination, water relations, and phenology of *Erythrina flabeljiformis* (Fabaceae) in southern Arizona. The Southwestern Naturalist. 25(4): 443–451.

Coop, J.D.; Schoettle, A.W. 2009. Regeneration of Rocky Mountain bristlecone pine (*Pinus aristata*) and limber pine. Forest Ecology and Management. 257(3): 893–903.

Cudworth, N.L.; Koprowski, J.L. 2011. Importance of scale in nest-site selection by Arizona gray squirrels. Journal of Wildlife Management. 75(7): 1668–1674.

Danzer, S.J.; Jemison, R.; Guertin, D.P. 2001. Riparian plant communities in the mountains of southeastern Arizona. The Southwestern Naturalist. 46(2): 191–199.

Darrow, R.A. 1950. The arboreal lichen flora of southeastern Arizona. The American Midland Naturalist. 43(2): 484–502.

Doust, S.J.; Erskine, P.D.; Lamb, D. 2006. Direct seeding to restore rainforest species: microsite effects on the early establishment and growth of rainforest tree seedlings on degraded land in the wet tropics of Australia. Forest Ecology and Management. 234(1–3): 333–343.

Dowling, P.M.; Clements, R.J.; McWilliam, R.J. 1971. Establishment and survival of pasture species from seeds sown on the soil surface. Australian Journal of Agricultural Research. 22(1): 61–74.

Dreesen, D.R. 2000. Survival and growth of containerized shrub seedlings six years after planting on Molycorp overburden piles 1994 study. In: New Mexico Plant Materials Center Annual Technical Report Year 2000. Los Lunas, NM: U.S. Department of Agriculture, Natural Resources Conservation Service: 47–53.

Epstein, E. 2002. Land application of sewage sludge and biosolids. Boca Raton, FL: CRC Press. 216 p.

Ferns, F.K.; Kleinman, L.H.; Postovit, B.C.; Steward, D.G.; Stowe, K.R.; Vicklund, L.E. 1996. Handbook of western reclamation techniques. Denver, CO: U.S. Department of the Interior, Office of Technology Transfer, Western Regional Coordinating Center, Office of Surface Mining. 504 p.

Fowler, N.L. 1988. What is a safe site? Neighbor, litter, germination date, and patch effects. Ecology. 69(4): 947–961.

Freeman, C.E.; Dick-Peddie, W.A. 1970. Woody riparian vegetation in the Black and Sacramento Mountain Ranges, southern New Mexico. The Southwestern Naturalist. 15(2): 145–164.

Frey, J.K.; Schwenke, Z.J. 2012. Mammals of Sugarite Canyon State Park, Colfax County, New Mexico. Occ. Pap. No. 311. Lubbock, TX: Museum of Texas Tech University. 408–416 p.

Golder Associates. 2004. 2003 Questa Mine test plot construction summary report. Submitted to Molycorp, Inc. Lakewood, CO: Golder Associates.

Granberry, D.M.; Kelley, W.T.; Langston, D.B.; Rucker, K.S.; Diaz-Perez, J.C. 2001. Testing compost value on pepper transplants. Biocycle. 42(10): 60–62.

Harmsen, G.W.; Kolenbrander, G.J. 1965. Soil inorganic nitrogen. In: Bartholomew, W.V.; Clark, F.E., eds. Soil nitrogen. Madison, WI: American Society of Agronomy: 43–92. Chapter 2.

Haussmann, N.S.; McGeoch, M.A.; Boelhouwers, J.C. 2010. Contrasting nurse plants and nurse rocks: the spatial distribution of seedlings of two sub-Antarctic species. Acta Oecologica. 36(3): 299–305.

Hine, S.; Harrington, J.T.; Dreesen, D.R. 1997. Seed scarification requirements for *Robinia neomexicana*. In: Harrington, J.T., ed. Proceedings, Third Annual Southwestern Container Growers Conference, Feb. 12–13, 1997. Fort Collins, CO.

Kay, B. 1978. Mulches for erosion control and plant establishment on disturbed sites. In: Kenny, S.T., ed. Proceedings, High Altitude Revegetation Workshop no. 3. Fort Collins, CO: Colorado State University, Environmental Resources Center: 182–203.

Khadduri, N.Y.; Harrington, J.T.; Murray, L. 2003. Percussion as an alternative seed treatment for *Robinia neomexicana*. Seed Science and Technology. 31(3): 561–570.

Kleier, C.; Lambrinos, J.G. 2005. The importance of nurse associations for three tropical alpine life forms. Arctic, Antarctic, Alpine Research. 37(5): 331–336.

Kleier, C.; Rundel, P.W. 2004. Microsite requirements, population structure and growth of the cushion plant *Azorella compacta* in the tropical Chilean Andes. Australian Ecology. 29(4): 461–470.

Kuhns, M.R. 1998. Trees of Utah and the Intermountain West: a guide to identification and use. Logan, UT: Utah State University Press. 341 p.

Ligneau, L.A.M.; Watt, T.A. 1995. The effects of domestic compost upon the germination and emergence of barley and six arable weeds. Annals of Applied Biology. 126(1): 153–162.

Lin, Y.; Wagner, M.R.; Seweyestewa, C.H.; Honahni, A.; DeGomez, M.; McMillin, J.D. 1996. Influence of cultural treatments on seed germination and seedling growth of *Robinia neomexicana*. Forest, Farm, and Community Tree Research Reports. 1(1): 112–116.

Little, S.; Cranmer, C.B.; Somes, H.A. 1958. Direct seeding of pitch pine in southern New Jersey: a progress report. Sta. Pap. NE-111. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 14 p.

Lyle, E.S. 1987. Surface mine reclamation manual. New York: Elsevier Science Publishing. 268 p.

Maestre, F.T.; Cortina, J.; Bautista, S.; Bellot, J.; Vallejo, R. 2003. Small-scale environmental heterogeneity and spatiotemporal dynamics of seedling establishment in a semiarid degraded ecosystem. Ecosystems. 6(7): 630–643.

Martin, T.E. 2007. Climate correlates of 20 years of trophic changes in a high-elevation riparian system. Ecology. 88(2): 367–380.

Martin, W.C.; Hutchins, C.R.1984. Spring wildflowers of New Mexico. Albuquerque, NM: University of New Mexico Press. 257 p.

Masrahi, Y.S.; Al-Yemeni, M.N.; Sayed, O.H. 2012. Nurse association of the stem succulent *Caralluma acutangula* in its natural habitat. Ekológia (Bratislava). 31(1): 46–53.

Maynard, A.A. 2000. Applying leaf compost to reduce fertilizer use in tomato production. Compost Science & Utilization. 8(3): 203–209.

Medina, A.; Martin, S. 1988. Stream channel and vegetation changes in sections of McKnight Creek, New Mexico. Great Basin Naturalist. 48(3): 373–381.

Mexal, J.G.; Fisher, J.T. 1987. Size hierarchy in conifer seedbeds. I. Time of emergence. New Forests. 1(3): 187–196.

Mexal, J.G.; Hawthorne, H.; Martinez, S.; Ulery, A.; Wagner, A. 2015. A 'seed gun' for high throughput percussion scarification of hard seed. Native Plants Journal. 16(1): 13–18.

Munn, L.; Harrington, N.; McGirr, D.R. 1987. Rock fragments. In: Williams, R.D.; Schuman, G.E., eds. Reclaiming mine soils and overburden in the Western United States: analytic parameters and procedures. Ankeny, IA: Soil Conservation Society of America: 259–282.

New Mexico State University (NMSU) Climate Center. 2012. ET calculator. http://nmclimate.nmsu.edu/evapotr/. (31 March 2015).

Niering, W.A.; Lowe, C.H. 1984. Vegetation of the Santa Catalina Mountains: community types and dynamics. Vegetatio. 58(1): 3–28.

Nobel, P.S.; Miller, P.M.; Graham, E.A. 1992. Influence of rocks on soil temperature, soil water potential, and rooting patterns for desert succulents. Oecologia. 92(1): 90–96.

Olson, D.F., Jr.; Karrfalt, R.P. 2008. *Robinia* L. Locust. In: Bonner, F.T.; Karrfalt, R.P., eds. The woody plant seed manual. Agriculture Handbook No. 727. Washington, DC: U.S. Department of Agriculture Forest Service. 969–973.

Ozores-Hampton, M.; Stoffella, P.J.; Bewick, T.A.; Cantliffe, D.J.; Obreza, T.A. 1999. Effect of age of cocomposted MSW and biosolids on weed seed germination. Compost Science & Utilization. 7(1): 51–57.

Parker, K.C. 1987. Site-related demographic patterns of organ pipe cactus populations in southern Arizona. Bulletin of the Torrey Botanical Club. 114(2): 149–155.

Parrish, T.L.; Anderson, S.H. 1994. Handbook of methods to reclaim wildlife habitat on surface mines in Wyoming. Laramie, WY: Wyoming Cooperative Fish and Wildlife Research Unit. 95 p.

Peters, E.M.; Martorell, C.; Ezcurra, E. 2008. Nurse rocks are more important than nurse plants in determining the distribution and establishment of globose cacti (*Mammillaria*) in the Tehuacán Valley, Mexico. Journal of Arid Environments. 72(5): 593–601.

Piccolo, A.; Mbagwu, J.S.C. 1990. Effects of different organic waste amendments on soil microaggregates stability and molecular sizes of humic substances. Plant & Soil. 123(1): 27–37.

Plummer, A.P. 1977. Revegetation of disturbed intermountain area sites. In: Thames, J.L., ed. Reclamation and use of disturbed land in the Southwest. Tucson, AZ: University of Arizona Press. 363 p.

Redente, E.F.; Mount, C.B.; Ruzzo, W.J. 1982. Vegetation composition and production as affected by soil thickness over retorted oil shale. Reclamation & Revegetation Research. 1(2): 109–122.

Resler, L.M.; Butler, D.R.; Malanson, G.P. 2005. Topographic shelter and conifer establishment and mortality in an alpine environment, Glacier National Park, Montana. Physical Geography. 26(2): 112–125.

Risse, L.M.; Bass, T.M.; Ritz, C.W. 2009. A review of Georgia's AFO regulations. Bulletin 1257. The University of Georgia, College of Agricultural and Environmental Sciences, Athens, GA. 8 p.

SAS Institute Inc. 2011. SAS/STAT® 9.3 User's Guide. Cary, NC: SAS Institute Inc. 8621 p. http://support.sas.com/documentation/cdl/en/statug/63962/HTML/default/viewer.htm#titlepage.htm. (12 August 2015).

Shaw, S.; Wels, C.; Robertson, A.; Lorinczi, G. 2002. Physical and geochemical characterization of mine rock piles at the Questa mine, New Mexico. In: Tailings and Mine Waste '02, proceedings of the Ninth International Conference on Tailings and Mine Waste. Fort Collins, CO: Springer-Verlag: 447–458.

Skartvedt, P.H. 2000. Woody riparian vegetation patterns in the Upper Mimbres watershed, southwestern New Mexico. The Southwestern Naturalist. 45(1): 6–14.

Tahboub, M. B. 2001. The effects of fertilization on shrub establishment and growth on high elevation overburden. Las Cruces, NM: New Mexico State University. M.S. thesis. 107 p.

Thornburg, A.A. 1982. Plant materials for use on surface mined lands in arid and semiarid regions. SCS-TP-157. EPA 600/7-79-134. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service. 88 p.

Toolin, L.J.; Van Devender, T.R.; Kaiser, J.M. 1979. The flora of Sycamore Canyon Pajarito Mountains Santa-Cruz County Arizona USA. Journal of Arizona-Nevada Academy of Science. 14(3): 66–74.

U.S. Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS). 2011. Assessing carbonates in the field with a dilute hydrochloric acid (HCl) solution. Soil Survey Technical Note 5. http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/ref/?cid=nrcs142p2_053572. (16 July 2015).

USDA NRCS. 2012. The PLANTS Database. Greensboro, NC: National Plant Data Team. http://plants.usda.gov. (19 February 2015).

U.S. Environmental Protection Agency (EPA). 2007. The use of soil amendments for remediation, revitalization and reuse. EPA 542-R-07-013. Washington, DC: U.S. Environmental Protection Agency, Office of Solid Waste, Technology Innovation Program. 59 p. http://www.epa.gov/aml/tech/compost.htm. (18 February 2014).

Vincent, D.W. 1996. Riparian restoration of Seiiorito Canyon, a tributary of the Rio Puerco. In: Shaw, D.W.; Finch, D.M., tech. coords. Desired future conditions for Southwestern riparian ecosystems: bringing interests and concerns together. Gen. Tech. Rep. RM-GTR-272. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 253–257.

Vogel, W.G. 1987. A manual for training reclamation inspectors in the fundamentals of soils and revegetation. Ankeny, IA: Soil and Water Conservation Society. 178 p.

Vogel, W.G.; Berg, W.A. 1973. Fertilizer and herbaceous cover influence establishment of direct-seeded black locust on coal-mine spoils. In: Hutnik, R.J.; Davis, G., eds. Ecology and reclamation of devastated land. Vol. 2. New York: Gordon and Breach. 189–198.

Wick, A.F.; Stahl, P.D.; Ingram, L.J. 2009. Aggregate-associated carbon and nitrogen in reclaimed sandy loam soils. Soil Science Society of America Journal. 73(6): 1852–1860.

Wollan, E.; Davis, R.D.; Jenner, S. 1978. Effects of sewage sludge on seed germination. Environmental Pollution. 17(3): 195–205.

Wood, M.K.; Buchanan, B.A. 2000. Reclamation considerations for arid regions of the Southwest receiving less than twenty-five centimeters annual precipitation. In: Barnhisel, R.I.; Darmody, R.G.; Daniels, W.L., eds. Reclamation of drastically disturbed lands. Monograph No. 41. Madison, WI: American Society of Agronomy: 303–322.

Wooton, E.O. 1913. Trees and shrubs of New Mexico. State College, NM: New Mexico College of Agriculture and Mechanic Arts. 159 p.

Upgrading Seed Lots of European Silver Fir (*Abies alba* Mill.) Using Imbibition-Drying-Separation

Shelagh A. McCartan and Richard L. Jinks

Seed Scientist, Forest Research, Forestry Commission, Alice Holt Lodge, Farnham, Surrey, United Kingdom; Project Leader, Forest Research, Forestry Commission, Alice Holt Lodge, Farnham, Surrey, United Kingdom

Abstract

A study was conducted to determine if imbibition-drying-separation (IDS) would adequately remove dead, empty, and insect-infested seeds to improve seed-lot quality of European silver fir (*Abies alba* Mill.). The seeds were placed in water and allowed to imbibe for 48 hr, dried for 1, 2, or 5 hr, and then separated into four fractions (A–D) per drying time using an air separator. The x-ray images showed that air separation was successful. Overall, an estimated 88 percent of filled seeds were recovered in fraction A after drying for 1 hr. The germination tests confirmed that the germination capacity of the upgraded fractions was higher than the bulk seed lot. Thus, IDS can be used to improve poor-quality seed lots, which would otherwise not be commercially viable for seedling production in container nurseries.

Introduction

European silver fir (*Abies alba* Mill.) produces good seed crops every 3 to 5 years. The seed crops often have a high proportion of empty seeds, which is largely because of poor pollination and seed pests such as chalcids (*Megastigmus suspectus*) and midges (*Resseliella piceae*) (Edwards 2008, Skrzypczyńska 1998, Wolf 2003). In most species, these empty and insect-infested seeds are removed during processing and cleaning of seed lots. Removing nonviable seeds, however, is possible only if filled and empty seeds differ in some physical characteristic that can be detected by mechanical or electrical means (Copeland and McDonald 1995). In *Abies* species, empty seeds sometimes have thickened seed coats or contain brown-black material that makes separation of filled and empty seeds by density very difficult. In addition to having a high proportion of empty seeds, *Abies* seeds also have resin vesicles that are susceptible to damage during processing. These resin vesicles contain terpenes that inhibit germination (Edwards 2008, Kolotelo 1997). In *Abies alba*, germination is often poor, ranging from 5 to 80 percent (Edwards 2008), which makes seedling production expensive and inefficient, particularly in container nurseries.

A three-stage process known as imbibition-drying-separation (IDS) can be used to improve tree seed-lot quality. This process is based on the principle that live seeds retain imbibed water more tightly than dead seeds when subjected to drying (Simak 1984a, 1984b). Thus, IDS exploits differential drying, which results in transient density differences so that live and dead seeds can be separated by various means (Gosling 2006, Karrfalt 1996). These include flotation in water, alcohol, or ether or by using an air separator or gravity table (Edwards 2008, Kolotelo 1997). IDS has been used successfully with several species, including lodgepole pine (*Pinus contorta* Dougl. ex. Loud.) (Simak 1984a), Scots pine (*P. sylvestris* L.) (Bergsten 1988), loblolly pine (*P. taeda* L.), and slash pine (*P. elliotii* Engelm.) (McRae et al. 1994). The IDS process is used operationally in Sweden (Karrfalt 1996, McRae et al. 1994). IDS has also been used successfully to remove seeds infested with chalcids (*Megastigmus spermotrophus)* from seed lots of Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) (Sweeney et al. 1991). Some species, such as longleaf pine (*Pinus palustris* Mill.), are not suited to separation by IDS because of their seed and wing characteristics (McRae et al. 1994). Seed processing is not a precise science, and tradeoffs are often made among seed quality, seed yield, and the amount of processing required to meet targets. The aim of this study was to evaluate the use of IDS to remove dead, empty, and insect-infested seeds and to determine its efficacy in improving seed-lot quality and increasing the germination capacity of European silver fir.

Materials and Methods

The key to IDS is to establish the baseline seed-lot quality, and then to track changes using a range of seed tests to determine if, how, and when the three-stage process improves poor seed lot quality.

Seed Source

In January 2014, a seed lot (250.0 kg [551.2 lb]) of European silver fir (aal.13[498]D1) from an elevation of 615 m (2,017 ft) was imported into the United Kingdom from the Brad-Poiana Neamtului region in Romania. The International Seed Testing Association, or ISTA, test certificate noted that the purity of the seed lot was 98.1 percent with the inert matter comprising wings, scales, needles, and resin. In addition, the seed lot contained 23 percent empty seeds and 64 percent viable seeds. Seed tests (described in the following section) were done on the bulk seed lot to establish a baseline for measuring the efficacy of IDS.

Imbibition-Drying-Separation

A 3.0-kg (6.6-lb) sample from the bulk seed lot was placed in a bucket of water, imbibed for 48 hr at 3.0 to 5.0 °C (37.4 to 41.0 °F), and then spin dried to remove excess water. The imbibed seeds were then split into three subsamples (1.2 kg [2.6 lb] each), spread in boxes with mesh bottoms, and then dried in a warm air stream for 1, 2, or 5 hr at 26.0 to 28.0 °C (78.8 to 82.4 °F). After drying, each subsample was randomly selected and separated by specific gravity into fractions using an air separator (Damas Lasti, Denmark). The air separator uses light suction, which is controlled by adjusting apertures in successive aspiration chambers, to separate seeds into three fractions comprising a clean fraction and two reject fractions. Because the air separator requires relatively large sample to operate, drying time was not replicated. For each drying time, the clean fraction was sent through the air separator two more times (figure 1). The corresponding reject fractions were

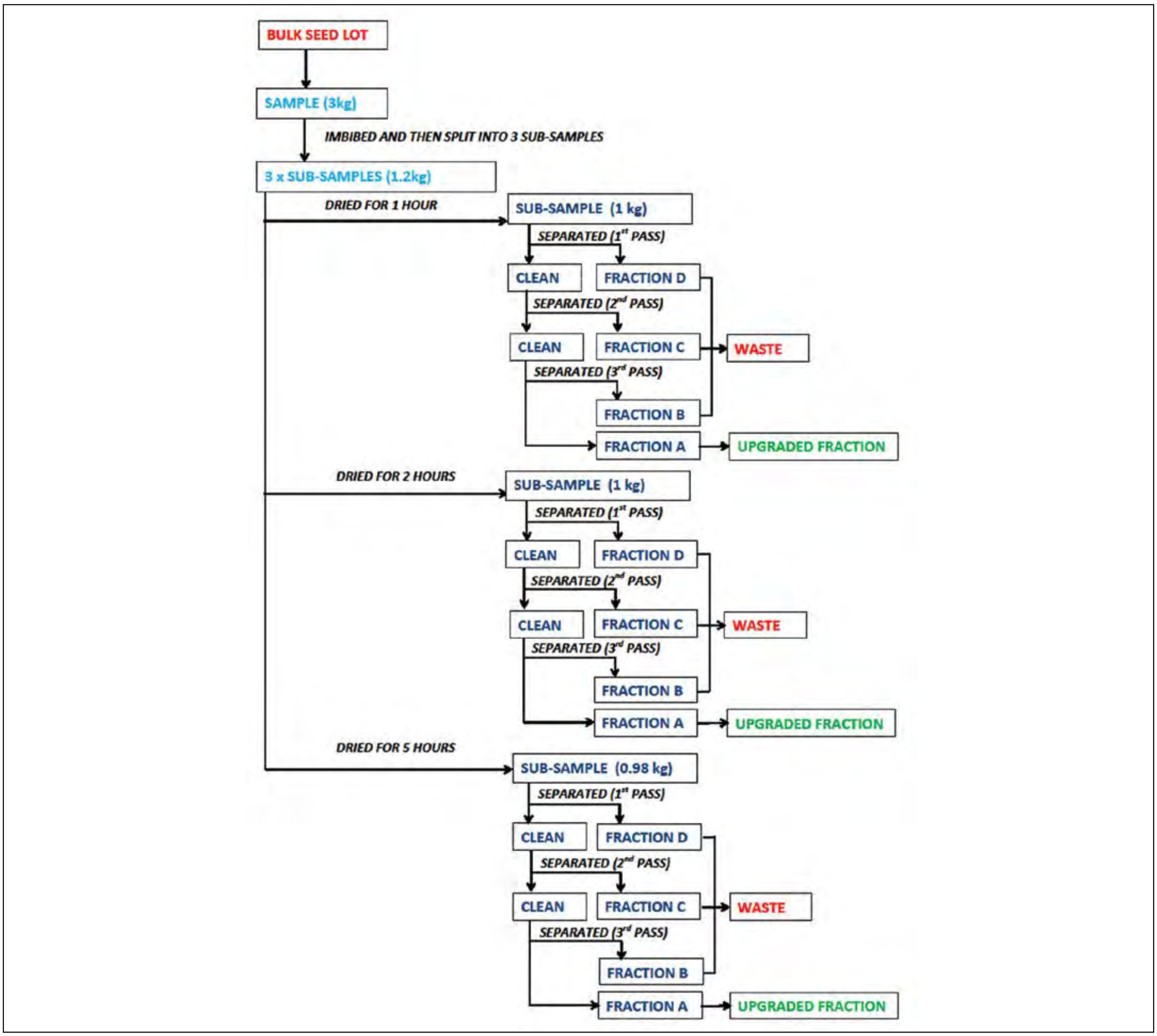


Figure 1. Flowchart of the imbibition-drying-separation (IDS) process.

combined to form fraction D after the first pass, fraction C after the second pass, and, finally, fraction B after the third pass, while the last clean fraction was fraction A. This process resulted in a total of four fractions (A–D) per drying time. Twenty seeds were then removed from each combination of drying time and fraction and weighed individually, confirming that fraction D had the lightest seeds and fraction A had the heaviest seeds.

Moisture Content

Before and after each drying time, moisture content (percentage fresh weight) was determined on four replicates of 10 seeds using the low-constant-temperature oven method (17 hr at 103.0 °C [217.4 °F]) (ISTA 2009). The change in moisture content over time provided an indication of the seeds' drying rate.

X-ray Tests

Six subsamples of 25 seeds were randomly selected from the bulk seed lot (control, before IDS) and each fraction (A–D) after each drying time and then x-rayed (20 kV for 10 sec). Seeds were scored into three categories (determined after assessing the x-ray images): filled, empty, or insect infested (figure 2). This scoring provided an indication of the separation accuracy resulting from the differential seed drying. Using these x-ray data, a recovery rate was calculated for all combinations of drying time and separation fraction. The recovery rate is a measure of the IDS success based on the amount of filled seed discarded in the reject or waste fractions; in this case, combined fractions B, C, and D. A recovery rate of 95 percent means that only 5 percent of filled seeds were lost as waste. Recovery rate was calculated using a formula by Jones et al. (2002), which was modified to account for differences in separation processes. An example of the formula used for the recovery rate of fraction A is given in the following equation:

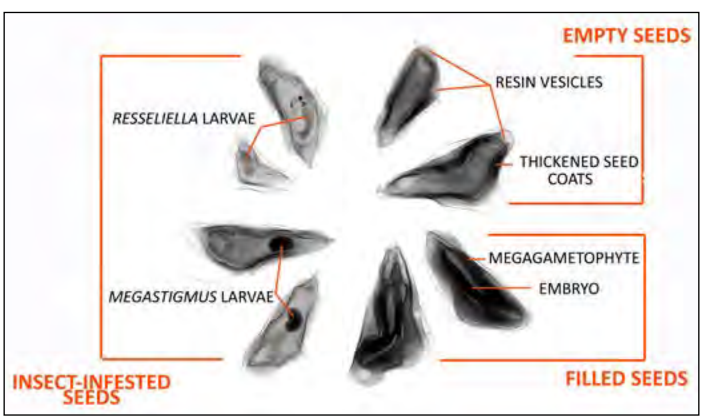


Figure 2. X-ray image showing filled, empty, and insect-infested seeds of European silver fir. (Photo by Shelagh McCartan, 2015)

$$Recovery\ rate\ (\%) = \frac{[P_{f=A} \times W_{f=A}]}{\Sigma[P_{f=A} \times W_{f=A}]...[P_{f=D} \times W_{f=D}]} \times 100$$

where P_f *= percent filled seeds in a fraction,* W_f *= weight of fraction.*

Germination Tests

A germination test was conducted to determine the proportion of seeds capable of producing normal seedlings under laboratory conditions. Two subsamples of 50 seeds from the bulk seed lot (control, before IDS) and each fraction (A–D) after each drying time were spread over filter papers, which were suspended above reservoirs of water in germination boxes. The seeds were chilled for 6 weeks at 3.0 to 5.0 °C (37.4 to 41.0 °F) and then incubated at 20.0 °C (68.0 °F) for a further 3 weeks. Germination was assessed two or three times per week for 21 days or until no further germination occurred over three consecutive assessments. Seeds were considered germinated when the radicle was 10.0 mm (0.4 in) long. Abnormal breached seedlings or those seedlings with stunted or necrotic roots (figure 3) were recorded but not included in the calculation of germination capacity (ISTA 2009). Germination capacity was calculated as a percentage of germinated seeds in each sample. After 21 days, ungerminated seeds were cut and scored as filled, empty, or insect infested.

Figure 3. Germinants included (a) normal seedlings, (b) "twin" seedlings, (c) abnormal breached seedlings, and (d) abnormal seedlings with stunted primary roots. (Photos by Shelagh McCartan, 2014–2015)

Data Analyses

The effect of drying time (three levels) and separation fraction (four levels) was determined on the number of seeds scored in each category (filled, empty, or insect-infested seeds) in x-ray and germination tests using the FITMULTINOMIAL procedure in Genstat 13 (Payne et al. 2009). Because the interaction between drying time and fraction was not replicated, only main effects of drying time and fraction were analyzed statistically by fitting a generalized linear model with multinomial distribution. Because subsamples were pseudoreplicates, the data were pooled for each combination of drying time and fraction. Sums of the three seed categories were constrained to the multinomial total and individual category counts modeled with a poisson error distribution and logarithm link function. Using the x-ray data, the significance of differences in the numbers of filled, empty and insect-infested seeds between fractions A, B, C, and D and the original bulk seed lot were then tested in turn using chi-square. Because the effect of drying time was nonsignificant, counts were pooled across drying time for each of fractions A, B, C, and D. For each chi-squared test, the goodness-of-fit for the numbers of seeds in each category between the fraction and the bulk (control) was analyzed as a one-way table with the expected numbers of seeds per fraction calculated from the proportions of filled, empty, and insect-infested seeds in the bulk seed lot (control). A Bonferroni correction was applied to adjust the cutoff of significant p-values to correct for the four comparisons.

Table 1. Weight (g [lb]) of each fraction after different drying times.

Seed fractions	Drying time (hours)		
	1	2	5
A	853 [1.9]	605 [1.3]	614 [1.4]
B	84 [0.2]	103 [0.2]	87 [0.2]
C	51 [0.1]	228 [0.5]	130 [0.3]
D	82 [0.2]	87 [0.2]	144 [0.3]

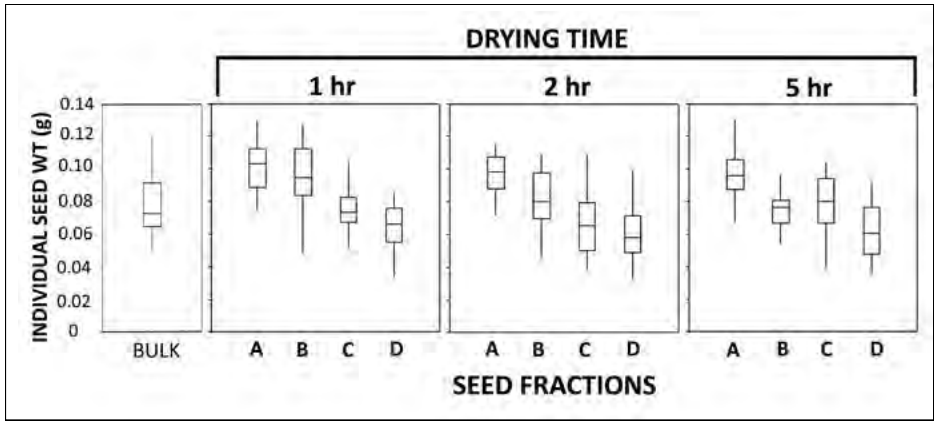


Figure 4. Box-and-whisker plot showing individual seed weights (g) for bulk seed lot (before imbibition-drying-separation [IDS]) and fractions (A–D) after drying for 1, 2, or 5 hr (n = 20). Fraction D separated out on the first pass, fraction C separated out on the second pass, and fractions B and A separated out on the third pass in the air separator.

Results

Moisture Content

At time 0, the bulk seed lot (control, before IDS) had a moisture content of 13.4 percent, increasing to 36.1 percent after imbibition (48 hr). Following drying treatments, seed moisture content decreased to 21.5 percent after 1 hr, 21.9 percent after 2 hr, and 14.7 percent after 5 hr.

Imbibition-Drying-Separation

After IDS, there were four fractions per drying time (12 in total). Based on weight, fraction A had significantly more seeds for each drying time than the other fractions, which were similar to one another (table 1). The largest fraction A (by weight) resulted after drying for 1 hr, which represented about 80 percent of the original subsample (table 1). Within each fraction, the weight of individual seeds varied significantly, with heaviest seeds usually occurring in fraction A and lightest seeds in fraction D (figure 4).

X-ray Tests

Before IDS, the original bulk seed lot contained 79 percent filled seeds, 14 percent empty seeds, and 7 percent insect-infested seeds (figure 5). After IDS, fraction had a significant effect on the number of seeds within each category ($p < 0.001$), but drying time did not have an effect ($p = 0.871$) (figure 5). Each fraction had significantly different overall proportions of filled, empty, and insect-infested seeds compared with the original bulk seed lot ($p < 0.001$ for all four fractions). Fraction A had more filled seeds (91 to 97 percent) but fewer empty and insect-infested seeds; fraction B had similar levels of filled seeds as the original bulk seed lot but it had more

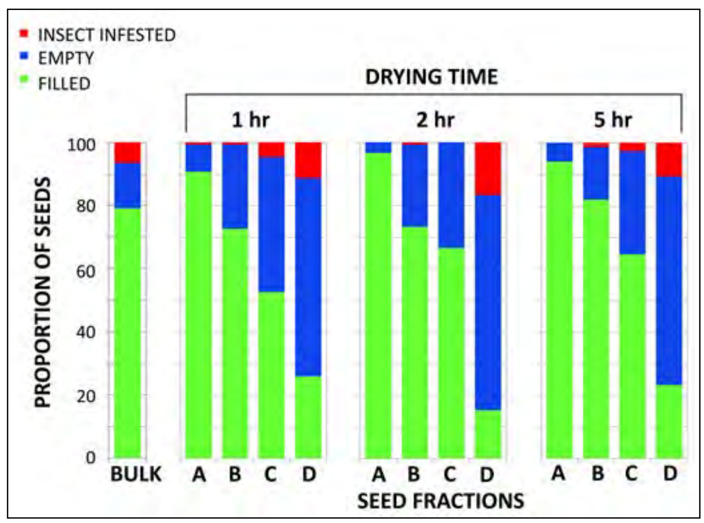


Figure 5. Proportion of filled, empty, and insect-infested seeds in the bulk seed lot (before imbibition-drying-separation [IDS]) and fractions after IDS determined from x-ray images. Fraction D separated out on the first pass, fraction C separated out on the second pass, and fractions B and A separated out on the third pass in the air separator.

empty and fewer insect-infested seeds; fractions C and D had fewer filled seeds than the original bulk seed lot. Fraction A had the highest recovery rate of filled seeds (88 percent) after drying for 1 hr (table 2). Fraction D contained the highest proportion of insect-infested seeds, regardless of drying time.

Table 2. Percentage recovery rate of filled seeds within each fraction after different drying times.

Seed fractions	Drying time (hours)		
	1	2	5
A	88	71	75
B	7	9	9
C	3	18	11
D	2	2	4

Germination Tests

Before IDS, the bulk seed lot had a germination capacity of 64 percent (figure 6). After IDS, the number of filled (including germinants), empty, or insect-infested seeds differed significantly for fraction ($p < 0.001$) but not for drying time ($p = 0.293$). In all cases, the germination capacity was highest in fraction A (71 to 81 percent) and lowest in fraction D (9 to 23 percent) (figure 6). In addition, seeds within fraction A tended to germinate earlier and more uniformly than those in the other fractions. A small proportion of seeds (< 12 percent) germinated prematurely during chilling, particularly in fraction A (figure 6).

Discussion

IDS has three stages: imbibition, drying, and separation. The process, however, is not precisely defined and each stage can be done in many ways (Gosling 2006). Drying, though, is the critical stage; if too short or too long, then seeds cannot be separated effectively on the basis of transient density differences. Seeds usually lose water rapidly early in the drying process, largely because of the loss of loosely bound bulk water in seeds. The partially dried seeds then lose water more slowly due to the reduced water potential difference between the seeds and the surrounding air. The drying rate, though, depends on seed viability as live seeds retain water more tightly than dead seeds. At some point, therefore, seeds have very different physical characteristics, such as moisture content, density, and electrical conductivity, which thereby enables improved seed separation based on viability (Gosling 2006, Karrfalt 1996, Simak 1984b). In this trial, the largest weight differential among individual seeds occurred after drying for 1 hr when the moisture content had decreased from 36.1 to 21.5 percent. Longer drying resulted in confounding of fractions B and C, particularly as seeds approached storage moisture content (9 to 12 percent). Drying time, therefore, is important as the efficiency of separation determines whether IDS is a commercially viable option for upgrading poor-quality seed lots.

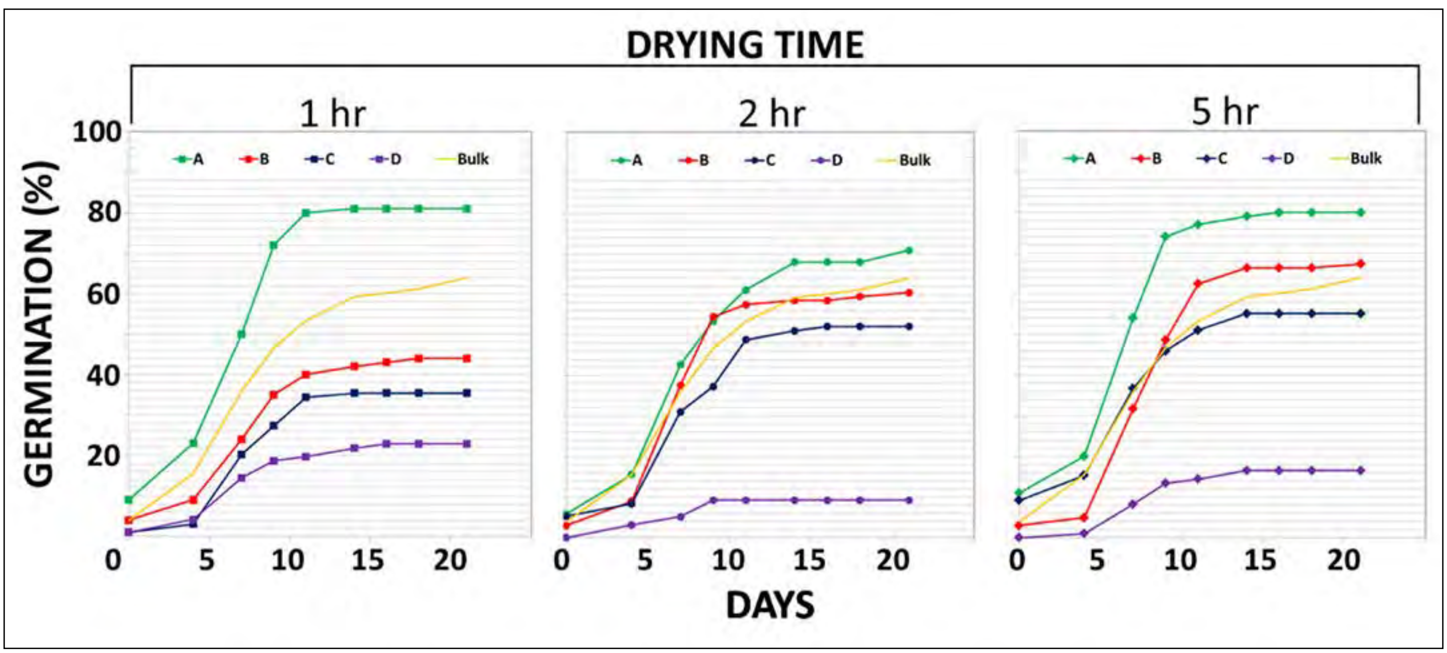


Figure 6. Germination capacity of the bulk seed lot (before imbibition-drying-separation [IDS]) and fractions after IDS. Fraction D separated out on the first pass, fraction C separated out on the second pass, and fractions B and A separated out on the third pass in the air separator.

In this trial, seed fractions were assessed using two seed tests. The x-ray test provided a quick, nondestructive snapshot of separation immediately after drying for 1, 2, or 5 hr. These x-ray images showed that fraction A contained mainly filled seeds, fractions B and C had varying proportions of filled and empty seeds, and fraction D had mostly empty and insect-infested seeds. It is not only the number of viable and nonviable seeds within separation fractions, however, that is important. The weight of the resulting fractions after drying also influences the percentage recovery rate. The highest recovery rate was estimated at 88 percent of filled seeds for fraction A after drying for 1 hr. This recovery rate means that 12 percent of filled seeds were discarded to produce this upgraded fraction, which therefore incurs additional costs per seed. The germination test confirmed that fraction A had a higher germination capacity than the bulk seed lot before IDS, especially after drying for 1 hr. In fraction A, the seeds also germinated faster and more uniformly than those in remaining fractions, which suggests that the resin vesicles sustained minimal damage during IDS. A small proportion of seeds produced abnormal breached seedlings, however, or seedlings with stunted, deformed roots in all fractions. This problem has been reported in other true fir species, including white fir (*Abies concolor* [Gord. & Glend.] Lindl. ex Hildebr.) (Kitzmiller et al. 1975, Kolotelo 1997).

Overall, this trial shows that IDS can be used successfully to upgrade seed lots of European silver fir. The tradeoff is that the cost per seed increases from approximately 1.0 to 1.2 cents (U.S.) because of the discarded waste (about 20 percent of bulk seed lot). A cost-benefit analysis, however, shows that the slightly higher cost per seed is offset by the improved cost efficiency of seedling production (table 3). In container nurseries, poor-quality seed lots result in a high proportion of empty cells, which is usually overcome by increasing the sowing factor (Karrfalt 2013, Kolotelo 1997). Double or triple sowing, though, not only requires more seeds but also requires more thinning of multiple seedlings per cell. Thinning, in turn, increases the risk of unintentional selection against slower germinating seed sources. In contrast, the potential benefits of single sowing the upgraded seed lot include a higher proportion of seedlings per tray at a lower fixed cost per viable seedling compared with the bulk seed lot (table 3). The seeds also germinate more quickly and uniformly because of improved seed vigor, potentially resulting in better seedling performance (Karrfalt 2013).

Conclusions

Bad seed is a robbery of the worst kind: for your pocket-book not only suffers by it, but your preparations are lost and a season passes away unimproved.

—George Washington (Brainyquote 2015).

This trial shows that IDS can be used successfully to improve the germination capacity of European silver fir seed lots. The potential benefits of these upgraded seed lots include the ability to single sow seeds, which germinate earlier and more uniformly than nonupgraded seed lots, and, therefore, potentially improve the cost efficiency of seedling production in container nurseries.

Address correspondence to—

Shelagh McCartan, Forest Research, Forestry Commission, Alice Holt Lodge, Farnham, Surrey, United Kingdom GU10 4LH; e-mail: shelagh.mccartan@forestry.gsi.gov.uk; phone: +44(0)300–067–5683.

Acknowledgments

The authors thank David Payne (Plant and Seed Supply, Forest Enterprise England) for processing the seed lot, Christine Tilbury (Forest Research) for identifying the insect larvae, Andy Peace (Forest Research) for checking statistical analyses, and Corinne Baker (Plant and Seed Supply, Forest Enterprise England) and Victoria Stokes (Forest Research) for constructive criticism of this article. The project was funded by Forest Enterprise England. The mention of equipment is for information only and does not constitute endorsement.

Table 3. Cost-benefit analysis of using upgraded seed lots in container nurseries.

No. of seeds sown per cell	No. of empty cells per 100 containers*		No. of seedlings produced per 100 containers* (+ surplus thinned)		Total seed cost per viable seedling (U.S. cents**)	
	Bulk	Upgraded	Bulk	Upgraded	Bulk	Upgraded
1	36	19	64	81	1.7	1.5
2	13	4	87 (53)	96 (77)	2.4	2.6
3	5	1	95 (190)	99 (198)	3.3	3.6

* Based on germination capacity of 64 percent for bulk and 81 percent for upgraded fraction A after drying for 1 hr.

** £1.00 ≈ $1.50—March 2015.

REFERENCES

Bergsten, U. 1988. Invigoration and IDS-sedimentation of *Pinus sylvestris* seeds from northern Finland. Silva Fennica. 22(4): 323–327.

Brainyquote. 2015. http://www.brainyquote.com/quotes/quotes/g/georgewash146841.html. (28 February).

Copeland, L.O.; McDonald, M.B. 1995. Principles of seed science and technology. 3rd ed. New York: Chapman and Hall. 409 p.

Edwards, D.G.W. 2008. *Abies* P. Mill. In: Bonner, F.T.; Karrfalt, R.P., eds. The woody plant seed manual. Agriculture Handbook No. 727. Washington, DC: U.S. Department of Agriculture, Forest Service: 149–198.

Gosling, P.G. 2006. IDS. In: Black, M.; Bewley, D.; Halmer, P., eds. The encyclopedia of seeds: science, technology and uses. Trowbridge, United Kingdom: Cromwell Press: 346.

International Seed Testing Association (ISTA). 2009. International rules for seed testing. In: Determination of moisture content. Basserdorf, Switzerland: International Seed Testing Association: 9.1–9.20. Chapter 9.

Jones, C.L.; Harrington, J.T.; Dreesen, D. 2002. Refinement and stratification of thinleaf alder and water birch seeds from New Mexico. Native Plants Journal 3(2): 142–150.

Karrfalt, R.P. 2013. The importance of good seed. In: Haase, D.L.; Pinto, J.R.; Wilkinson, K.M., tech. coords. National proceedings, forest and conservation nursery associations. Proceedings RMRS-P-69. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 49–52.

Karrfalt, R.P. 1996. Upgrading seeds with IDS: a review of successes and failures. In: Landis, T.D.; South, D.B., tech. coords. National proceedings, forest and conservation nursery associations. Gen. Tech. Rep. PNW-GTR-389. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 183–186.

Kitzmiller, J.H.; Helms, J.A.; Stover, P. 1975. Influence of seed treatment of germination of *Abies concolor* and *A. magnifica*. Int. Rep. 3. Berkley: University of California, School of Forestry and Conservation/True Fir Management Cooperative. 16 p.

Kolotelo, D. 1997. *Abies* seed problems. In: Proceedings, 1997 Forest nursery association of British Columbia. Surrey, BC: 1–12.

McRae, J.B.; Bergsten, U.; Lycksell, S. 1994. The use of the IDS-treatment on southern pine seeds and its effect on seed cost and efficiency in the seed bed. In: Landis, T.D.; Dumroese, R.K., tech. coords. Proceedings, forest and conservation nursery associations. Gen. Tech. Rep. RM-GTR-257. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 73–79.

Payne, R.W.; Murray, D.A.; Harding, S.A.; Baird, D.B.; Soutar, D.M. 2009. GenStat for windows (13th Edition) introduction. VSN International, Hemel Hempstead.

Simak, M. 1984a. A method for removal of filled-dead seeds from a sample of *Pinus contorta*. Seed Science and Technology. 12(3): 767–775.

Simak, M. 1984b. Method for sorting of seed. United States Patent 4,467,560. http://www.google.co.uk/url?url=http://patentimages.storage.googleapis.com/pdfs/US4467560.pdf&rct=j&frm=1&q=&esrc=s&sa=U&ei=FyUmVYeBCoHraKXygqAF&ved=0CCAQFjAC&usg=AFQjCNG9730OkWXJk-haqKZ6Zs5zXSBzBA. (1 April 2015).

Skrzypczyńska, M. 1998. Relationships between the number of seeds in the cones of *Abies alba* Mill. and their infestation with *Megastigmus suspectus* Borr. (Hym., Torymidae). Journal of Applied Entomology. 122(1–5): 145–148.

Sweeney, J.D.; El-Kassaby, Y.A.; Taylor, D.W.; Edwards, D.G.W.; Millers, G.E. 1991. Applying the IDS method to remove seeds infested with the seed chalcid, *Megastigmus spermotrophus* Wachtl, in Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco. New Forests. 5(4): 327–334.

Wolf, H. 2003. EUFORGEN technical guidelines for genetic conservation and use for silver fir (*Abies alba*). Rome, Italy: International Plant Genetic Resources Institute. 6 p.

Forest Nursery Seedling Production in the United States—Fiscal Year 2014

George Hernández, Richard A. Harper, Kea J. Woodruff, Scott Enebak, Ronald P. Overton, Jennifer Lesko, and Diane L. Haase

Regional Regeneration Specialist, U.S. Department of Agriculture (USDA), Forest Service, Atlanta, GA; Forest Resource Analyst (retired), USDA Forest Service, Clemson, SC; Nursery Production and Logistics Associate, Center for Forest Nursery and Seedling Research, University of Idaho, Moscow, ID; Director, Southern Forest Nursery Management Cooperative, School of Forestry and Wildlife Sciences, Auburn University, Auburn, AL; Area Regeneration Specialist, USDA Forest Service, West Lafayette, IN; Graduate Student, Purdue University, West Lafayette, IN; Western Nursery Specialist, USDA Forest Service, Portland, OR

Background

This annual report summarizes forest nursery seedling production in the United States. The number of seedlings reported is used to estimate the number of acres of forest planting per year. Prepared by the U.S. Department of Agriculture (USDA), Forest Service, Forest Inventory and Analysis (FIA) and State and Private Forestry (S&PF), this report includes State-by-State breakdowns, regional totals, and an analysis of data trends. Universities located in the southern, northeast, and western regions of the United States made an effort to collect data from all the major producers of forest and conservation seedlings in the 50 States. Forest and conservation nursery managers provided the information presented in this report. As far as we know, it is the most complete compilation of such data in the country. Because all data are provided voluntarily by outside sources and some data are estimated, however, caution must be used in drawing inferences.

Methodology

The empirical data for this report were produced by S&PF in collaboration with Auburn University, the University of Idaho, and Purdue University. All of these universities collected forest tree seedling production data directly from the forest and conservation nurseries that grow forest tree seedlings in their region of the United States (Auburn University collected from 12 States in the Southeast, the University of Idaho collected from 17 States in the West, and Purdue University collected from 21 States in the Northeast and Midwest). The approximation of planted acres for each State is derived from FIA estimates of tree planting area based on ground plots collected by States during 5-, 7-, or 10-year periods and compiled as an average annual estimate for the associated period. FIA estimates of acres of trees planted by State may not correlate with the estimates produced by nursery production surveys because nurseries do not report shipments across State lines. Total acres by region, however, provide a reasonable comparison between the two methods. Data collected are reported by hardwood and conifer seedlings produced and acreage planted of each (table 1) and by bareroot and container seedlings produced (table 2). A complete list of the assumptions used in compiling this report appears in the *Forest Nursery Seedling Production in the United States—Fiscal Year 2013* (Harper et. al. 2014).

Table 1. Hardwood and conifer tree seedling production and acres planted for each State and each region during the 2013–2014 planting year.

State	Hardwood seedlings produced	Hardwood acres planted	Conifer seedlings produced	Canadian conifer imports	Conifer acres planted[1]	Total seedlings produced	Total acres planted[1]	FIA data acres planted[12]
				Southeast				
Florida[2]	1,760,000	3,200	40,696,000	—	73,993	42,456,000	77,193	140,247
Georgia[2]	8,762,500	15,932	316,180,800	—	574,874	324,943,300	590,806	196,602
North Carolina[2]	576,800	1,049	72,223,000	—	131,315	72,799,800	132,363	108,286
South Carolina[2]	3,950,420	7,183	119,182,430	—	216,695	123,132,850	223,878	55,479
Virginia[2]	507,000	922	28,728,000	—	52,233	29,235,000	53,155	92,707
Regional totals	**15,556,720**	**28,285**	**577,010,230**	**—**	**1,049,110**	**592,566,950**	**1,077,394**	**593,320**
				South Central				
Alabama[2]	483,500	879	117,530,500	—	213,692	118,014,000	214,571	263,720
Arkansas[2]	9,222,700	16,769	102,195,500	—	185,810	111,418,200	202,579	156,973
Kentucky[2]	1,472,200	2,677	133,904	—	243	1,606,104	2,920	1,479
Louisiana[2]	1,771,700	3,221	12,731,000	—	23,147	14,502,700	26,369	166,984
Mississippi[2]	972,400	1,768	82,173,000	—	149,405	83,145,400	151,173	192,746
Oklahoma[2]	535,300	973	2,281,900	—	4,149	2,817,200	5,122	25,434
Tennessee[2]	1,654,000	3,007	5,949,000	—	10,816	7,603,000	13,824	22,489
Texas[2]	65,000	118	83,825,900	—	152,411	83,890,900	152,529	113,125
Regional totals	**16,176,880**	**29,413**	**406,820,540**	**—**	**739,674**	**422,997,504**	**769,086**	**942,949**
				Northeast				
Connecticut	—	—	—	—	—	—	—	—
Delaware	—	—	—	—	—	—	—	—
Maine[2, 11]	—	—	—	3,220,000	5,855	3,220,000	5,855	8,284
Maryland[2]	2,223,300	4,042	1,255,700	—	2,283	3,479,000	6,325	—
Massachusetts	—	—	—	—	—	—	—	—
New Hampshire[2]	11,085	20	145,500	—	265	156,585	285	—
New Jersey[2]	102,800	187	84,900	—	154	187,700	341	—
New York[9]	118,000	131	644,000	—	716	762,000	847	203
Pennsylvania[2]	1,701,035	3,093	2,639,061	—	4,798	4,340,096	7,891	1,391
Rhode Island	—	—	—	—	—	—	—	—
Vermont	—	—	—	—	—	—	—	—
West Virginia[2]	679,850	1,236	91,525	—	166	771,375	1,403	—
Regional totals	**4,836,070**	**8,709**	**4,860,686**	**3,220,000**	**14,237**	**12,916,756**	**22,947**	**9,878**
				North Central				
Illinois[8]	1,044,660	2,402	210,600	—	484	1,255,260	2,886	5,062
Indiana[4]	2,898,428	4,459	1,098,713	—	1,690	3,997,141	6,149	1,331
Iowa[5]	797,200	1,329	92,700	—	155	889,900	1,483	—
Michigan[10, 11]	2,044,774	3,718	38,630,896	450,000	39,081	41,125,670	42,799	11,899
Minnesota[5, 11]	721,000	1,311	8,245,000	4,000,000	20,408	12,966,000	21,719	20,059
Missouri[3]	1,310,610	3,013	582,665	—	1,339	1,893,275	4,352	—
Ohio[3]	13,000	30	—	—	—	13,000	30	3,775
Wisconsin[6, 11]	1,418,910	1,774	7,008,505	2,200,000	11,511	10,627,415	13,285	9,413
Regional totals	**10,248,582**	**18,035**	**55,869,079**	**6,650,000**	**74,669**	**72,767,661**	**92,703**	**51,540**
				Great Plains				
Kansas[2]	88,925	162	146,000	—	265	234,925	427	—
Nebraska[2]	112,000	204	1,493,249	—	2,715	1,605,249	2,919	—
North Dakota[2]	20,500	37	1,252,000	—	2,276	1,272,500	2,314	—
South Dakota[2]	661,156	1,202	351,364	—	639	1,012,520	1,841	—
Regional totals	**882,581**	**1,605**	**3,242,613**	**—**	**5,896**	**4,125,194**	**7,500**	**0**
				Intermountain				
Arizona[2]	46,000	84	—	—	—	46,000	84	—
Colorado[2]	40,000	73	550,000	—	1,049	590,000	1,122	—
Idaho[2]	354,792	645	4,572,175	—	8,313	4,926,967	8,958	4,287
Montana[2]	249,934	454	816,002	—	1,484	1,065,936	1,938	5,142
Nevada[2]	5,500	10	4,000	—	7	9,500	17	—

Table 1. Hardwood and conifer tree seedling production and acres planted for each State and each region during the 2013–2014 planting year. (continued)

State	Hardwood seedlings produced	Hardwood acres planted	Conifer seedlings produced	Canadian conifer imports	Conifer acres planted[1]	Total seedlings produced	Total acres planted[1]	FIA data acres planted[12]
Intermountain (continued)								
New Mexico[2]	17,900	33	35,000	—	64	52,900	97	—
Utah	—	—	—	—	—	—	—	—
Wyoming	—	—	—	—	—	—	—	—
Regional totals	**714,126**	**1,229**	**5,977,177**	**—**	**10,917**	**6,691,303**	**12,216**	**9,429**
Alaska								
Alaska	—	—	—	—	—	—	—	806
Pacific Northwest								
Oregon[7, 13]	1,335,000	3,814	49,343,302	5,272,227	156,044	55,950,529	159,858	88,379
Washington[7, 13]	969,169	2,769	53,021,617	5,272,227	166,554	59,263,013	169,323	54,179
Regional totals	**2,304,169**	**6,583**	**102,364,919**	**10,544,454**	**322,598**	**115,213,542**	**329,181**	**142,558**
Pacific Southwest								
California[8]	—	—	16,300,000	—	36,222	16,300,000	36,222	29,535
Hawaii[8]	82,281	183	—	—	—	82,281	183	—
Regional totals	**82,281**	**183**	**16,300,000**	**—**	**36,222**	**16,382,281**	**36,405**	**29,535**
Totals	**50,801,409**	**94,041**	**1,172,445,244**	**20,414,454**	**2,253,322**	**1,243,661,191**	**2,347,433**	**1,779,209**

[1] Acres planted were estimated assuming:

[2] 550 stems/ac.

[3] 435 stems/ac.

[4] 650 stems/ac.

[5] 600 stems/ac.

[6] 800 stems/ac.

[7] 350 stems/ac.

[8] 450 stems/ac.

[9] 900 stems/ac.

[10] 1,000 stems/ac.

[11] Totals include an estimate of conifers produced in Canada for distribution to neighboring States; bareroot imports for Maine and container for other States.

[12] Average annual acreage planted estimated for all States (2012) on 5-year cycles, except Alaska, Louisiana, Mississippi, and North Carolina are on 7-year cycles and Arizona, California, Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, Oregon, and Washington are on 10-year cycles; data generated by R. Harper.

[13] Totals include an estimate of conifers imported from Canada to Oregon and Washington (total amount divided evenly between the two States).

Table 2. Bareroot and container tree seedling production for each State and each region during the 2013–2014 planting year.

State	Bareroot	Container	Total seedlings produced
Southeast			
Florida	36,787,000	5,669,000	42,456,000
Georgia	171,533,500	153,409,800	324,943,300
North Carolina	55,342,800	17,457,000	72,799,800
South Carolina	121,637,850	1,495,000	123,132,850
Virginia	29,235,000	—	29,235,000
Regional totals	**414,536,150**	**178,030,800**	**592,566,950**
South Central			
Alabama	111,846,000	6,168,000	118,014,000
Arkansas	111,418,200	—	111,418,200
Kentucky	1,534,104	72,000	1,606,104
Louisiana	14,052,700	450,000	14,502,700
Mississippi	75,190,400	7,955,000	83,145,400
Oklahoma	2,743,400	73,800	2,817,200
Tennessee	7,603,000	—	7,603,000
Texas	83,890,900	—	83,890,900
Regional totals	**408,278,704**	**14,718,800**	**422,997,504**

Table 2. Bareroot and container tree seedling production for each State and each region during the 2013–2014 planting year. (continued)

State	Bareroot	Container	Total seedlings produced
		Northeast	
Connecticut	—	—	—
Delaware	—	—	—
Maine	—	—	—
Maryland	3,479,000		3,479,000
Massachusetts	—	—	—
New Hampshire	156,585		156,585
New Jersey	187,700		187,700
New York	735,500	26,500	762,000
Pennsylvania	3,629,096	711,000	4,340,096
Rhode Island	—	—	—
Vermont	—	—	—
West Virginia	771,375	—	771,375
Canada	3,220,000	—	3,220,000
Regional totals	**12,179,256**	**737,500**	**12,916,756**
		North Central	
Illinois	1,252,500	2,760	1,255,260
Indiana	3,833,891	163,250	3,997,141
Iowa	889,900	—	889,900
Michigan	40,009,550	666,120	40,675,670
Minnesota	6,176,000	2,790,000	8,966,000
Missouri	1,893,275	—	1,893,275
Ohio	—	13,000	13,000
Wisconsin	8,424,765	2,650	8,427,415
Canada	—	6,650,000	6,650,000
Regional totals	**62,479,881**	**10,287,780**	**72,767,661**
		Great Plains	
Kansas		234,925	234,925
Nebraska	870,000	735,249	1,605,249
North Dakota	1,200,000	72,500	1,272,500
South Dakota	997,501	15,019	1,012,520
Regional totals	**3,067,501**	**1,057,693**	**4,125,194**
		Intermountain	
Arizona	—	46,000	46,000
Colorado	—	590,000	590,000
Idaho	1,856,792	3,070,175	4,926,967
Montana	18,050	1,047,886	1,065,936
Nevada	—	9,500	9,500
New Mexico	—	52,900	52,900
Utah	—	—	—
Wyoming	—	—	—
Regional totals	**1,874,842**	**4,816,461**	**6,691,303**
		Alaska	
Alaska	—	—	—
		Pacific Northwest	
Oregon	26,914,219	23,764,083	50,678,302
Washington	31,720,283	22,270,503	53,990,786
Canada		10,544,454	10,544,454
Regional totals	**58,634,502**	**56,579,040**	**115,213,542**
		Pacific Southwest	
California	—	16,300,000	16,300,000
Hawaii	—	82,281	82,281
Regional totals	**—**	**16,382,281**	**16,382,281**
Total	**961,050,836**	**282,610,355**	**1,243,661,191**

Data Trends

A total of 1,217,607,888 forest tree seedlings were shipped from forest and conservation nurseries in the United States in fiscal year (FY) 2014, an increase of 36,053,353 (3 percent) over the forest nursery seedling reported for FY 2013 (Harper et al. 2014). Based on the total number of seedlings shipped and the average number of seedlings planted per acre in each State, we estimate that approximately 2,347,957 ac (950,184 ha) of trees were planted during the fall 2013 through spring 2014 planting season, a 3-percent increase compared with the number of acres reported for the previous planting season (Harper et al. 2014). Trends by regions (table 3) are as follows:

West—The 17 States in the USDA Forest Service western regions produced approximately 45 million more seedlings than in the FY 2013 planting season and 11 percent of the U.S. total. This increase, however, is overestimated, because Canadian import estimates were not available for the FY 2013 report.

East—The 20 States in the USDA Forest Service Northeastern Area reported 85 million seedlings, a decrease of 16 million seedlings over the FY 2013 planting season and 7 percent of the U.S. total. The decrease in seedlings reported appears to be a normal fluctuation.

South—The 13 States in the USDA Forest Service Southern Region produced more than 1 billion forest tree seedlings (82 percent of the U.S. total), an increase of 32 million over the FY 2013 planting season.

Overall, forest nursery seedling production increased during the past 3 years (table 3). This trend seems consistent with the steady improvement in the economy during this period. Timber markets continue to be sluggish.

Table 3. Total forest nursery seedling production in each region from FY 2012 to FY 2014.

Year	Total seedling production	West	East	South
FY 2014	1,243,661,191	142,412,320	85,684,417	1,015,564,454
FY 2013	1,181,554,535	96,344,063	102,066,671	983,143,801
FY 2012	1,190,552,819	170,975,830	81,672,547	936,918,542

FY = fiscal year.

Sources: This report and Harper et al. (2013, 2014)

Address correspondence to—

George Hernández, Regional Regeneration Specialist, U.S. Department of Agriculture, Forest Service, State and Private Forestry, 1720 Peachtree Road NW, Atlanta, GA 30309; e-mail: ghernandez@fs.fed.us; phone: 404–347–3554.

Acknowledgments

The authors thank the U.S. Department of Agriculture, Forest Service, Washington Offices of the Forest Inventory and Analysis program and the State and Private Forestry Deputy Area for their support.

REFERENCES

Harper, R.A.; Hernandez, G.; Arsenault, J.; Bryntesen, M.; Enebak, S.; Overton, R.P. 2013. Forest nursery seedling production in the United States—fiscal year 2012. Tree Planters' Notes. 56(2): 72–75.

Harper, R.A.; Hernandez, G.; Arsenault, J.; Woodruff, K.J.; Enebak, S.; Overton, R.P.; Haase, D.L. 2014. Forest nursery seedling production in the United States—fiscal year 2013. Tree Planters' Notes. 57(2): 62–66.

Inoculation of Fumigated Nursery Beds and Containers With Arbuscular Mycorrhizal Products for Eastern Redcedar Production

Michelle M. Cram and Stephen W. Fraedrich

Plant Pathologist, U.S. Department of Agriculture (USDA), Forest Service, Forest Health Protection, Athens, GA; Research Plant Pathologist, USDA Forest Service, Southern Research Station, Athens, GA

Abstract

Commercially available arbuscular mycorrhizal (AM) products were applied at an operational rate to eastern redcedar (*Juniperus virginiana* L.) nursery beds and containers to evaluate seedling growth and colonization responses. A field study at the Augusta Forestry Center in Crimora, VA, and a companion container study were initiated in the fall of 2012. MycoApply® Endo products containing the same four species of AM fungi were applied as a liquid, granular, or seed treatment. The field application of AM products did not result in early root colonization by AM fungi. By November 2013, seedlings were colonized by naturally occurring AM fungi and seedlings did not differ in size among treatments. A winter rye cover crop treatment tested in conjunction with the AM treatments in the container study did not significantly affect AM colonization. AM colonization of seedling roots was very low in container seedlings from all treatments and no growth response could be attributed to AM fungi. This paper was presented at a joint meeting of the Northeast Forest and Conservation Nursery Association and Southern Forest Nursery Association (Williamsburg, VA, July 21–24, 2014).

Introduction

Many forest nurseries in the South grow eastern redcedar (*Juniperus virginiana* L.) as a minor use specialty crop. Seedlings of eastern redcedar are commonly used in the South for establishing Christmas tree farms, wildlife habitat areas, windbreaks, and other soil stabilization projects. Growing this conifer species unfortunately has presented challenges for nursery managers. One of the most documented causes of redcedar seedling losses has been Phomopsis blight, caused by the fungus *Phomopsis juniperovora* Hahn (Otta et al. 1980). Stunting also results in poor crops in which no biological pests are found (figure 1). One theory regarding the cause of periodic stunting in eastern redcedar is that fumigation before sowing removes the arbuscular mycorrhizal (AM) fungi from the seedling root zone.

Figure 1. Eastern redcedar stunting due to unknown causes. (Photo by Michelle Cram, 2009)

Arbuscular mycorrhizae are the result of a symbiotic association between an endomycorrhizal fungus and a plant root. AM fungi take carbon from the plant host and increase nutrient uptake and drought tolerance of the host (Allen et al. 2003). The presence of AM roots on eastern redcedar is believed to enhance the ability of this species to thrive under low-fertility environments (Williams et al. 2013). The effects of fumigation and AM colonization on eastern redcedar growth in nurseries have not been studied; however, applications of AM-type mycorrhizae mixtures can increase seedling growth of cade juniper (*Juniperus oxycedrus* L.) (Alguacil et al. 2006). There is also evidence that many other tree species dependent on endomycorrhizae have reduced growth when AM fungi are absent or colonization is delayed (Berch et al. 1991; Bryan and Kormanik 1977; Douds and Chaney 1982; Kormanik et al. 1977, 1982). Commercial AM inoculants are available for use in forest nurseries and are being used on a routine basis for some species (Amaranthus and Steinfeld 2005, Carpio et al. 2003, Meikle and Amaranthus 2008). Tests of various commercially available AM products have shown that seedling growth responses can be positive to AM inoculations; however, they also show a high degree of specificity between individual host species and the AM product applied (Carpio et al. 2003, Corkidi et al. 2005). From these few studies, it is evident that managers should test AM products on a given species before operational use to determine if the product provides enough benefit to warrant the cost.

The purpose of this study was to evaluate commonly used mycorrhizal products on eastern redcedar in a forest nursery field site at operational application rates. A container study was also conducted in a growth chamber under similar rates and conditions as the field study. The nursery that participated in this study uses a winter rye (*Secale cereale* L.) cover crop to protect seedbeds from frost heaving and other severe weather conditions. Because of this practice, a winter rye cover crop treatment was also added to the container study to evaluate potential effects on AM colonization of seedling roots and subsequent growth response of seedlings.

Methods

Field Study

Several nursery beds were used at the Augusta Forest Center Nursery in Crimora, VA, to evaluate three formulations of MycoApply® Endo products (Mycorrhizal Applications, Inc., Grants Pass, OR) applied to soil or to seed before sowing the beds with eastern redcedar. A control treatment was also established for comparison. Seeds were obtained from the F.W. Schumacher Company (Sandwich, MA) and were from an Eastern U.S. coastal source. The field soil was a loam (46:32:22 sand:silt:clay) with 2.7 percent organic matter. The study area was fumigated in October 2012 at 400 lb/ac (448 kg/ha) with 80:20 methyl bromide:chloropicrin. Rye seed used as a cover crop was from Discount Seeds (Watertown, SD, Lot 12232).

On October 25, 2012, three commercial formulations of MycoApply® (table 1) were applied to the field or to the seeds just before sowing. Treatment plots were 4.00 ft wide by 30.00 ft long (1.22 m by 9.15 m), and each treatment was replicated four times in a randomized complete block design. The AM species listed on the labels of all three MycoApply® products used in this study have been recently undergoing taxonomic reclassifications. According to Redecker et al. (2013), the Schüßler and Walker (2010) taxonomic treatment of the AM species is generally accepted for this group of fungi and, therefore, will be the primary authority to name the AM species used in this study. Each MycoApply® formulation included equal parts of *Glomus aggregatum* Schenck and Smith, *Funneliformis mosseae* (= *G. mosseae* Nicol. and Gerd.), *Rhizophagus intraradices* (= *G. intraradices* Schenck and Smith), and *Claroideoglomus etunicatum* (= *G. etunicatum* Becker and Gerd.). The application rate for all three products was based on the recommended field rate for the Liquid Endo at 3.0 gal (11.3 L), or 10.8 million AM propagules, per 100,000 seedlings. Eastern redcedar was sown at a rate to obtain a seedling density of approximately 10.0 seedlings/ft^2 (107.5/m^2), and, therefore, the liquid and granular formulations were applied at 1,080 AM propagules/ft^2 (11,613 propagules/m^2) surface area and rototilled into the soil. The seed treatment was applied at a rate equivalent to 1,080 AM propagules/ft^2 (11,613 propagules/m^2) by mixing 68.0 ml (2.3 oz) of the AM seed treatment with 1.20 lb (0.54 kg) of eastern redcedar seeds, which was sown over 480.0 ft^2 (44.6 m^2). The winter rye was sown at 1.23 lb/480.0 ft^2 (0.56 kg/44.6 m^2) in all the treatments.

Table 1. Three commercial arbuscular mycorrhizal (AM) formulations of MycoApply® evaluated for eastern redcedar seedling production.

MycoApply® AM product	AM propagules	Cost in 2012
Liquid Endo	3,600,000 propagules/gal	$619/gal
Endo Granular	60,000 propagules/lb	$6.49/lb
Liquid Endo (Seed & Furrow)	3,600,000 propagules/16 oz	$619/16 oz

Nursery personnel applied glyphosate on March 23, 2013, to kill the winter rye. Beginning May 30, fertilizer was applied at 100 lb/ac (112 kg/ha) every 2 weeks as a liquid until mid-August. The fertilizer applications were alternated between formulations of 30 percent nitrogen, and an 8 percent sulfur + 9 percent nitrogen fertilizer mix. Pesticide applications included a Pyrethrin application on April 3, 2013, and prothioconazole applications beginning April 3, 2013, and rotated with thiophanate-methyl every 2 to 3 weeks, as weather permitted, throughout the summer for control of Phomopsis blight.

On June 13, 2013, 8 weeks after emergence, redcedar seedling density was determined. Three subplots per treatment plot were counted using a 1.0 by 4.0 ft (0.3 x 1.2 m) frame. Ten seedlings per plot were collected randomly in between counting frames to assess mycorrhizal colonization of roots. Samples were placed in a cooler and kept at 40 °F (4 °C) until processed. In the laboratory, the AM root colonization was assessed by clearing and staining roots with a modified procedure outlined by Kormanik et al. (1980a). Roots from the 10 seedlings in each treatment plot were cut into 0.59 in (1.50 cm) pieces. A 0.05 oz (1.50 g) subsample of roots from the ten seedlings was soaked in 10% (w/v) KOH for 60 minutes at 194 °F (90 °C). Roots were then soaked for 60 min in an alkaline hydrogen peroxide solution (3 ml of NH_4OH and 30 ml of 10% H_20_2 in 567 ml of water) for additional clearing. Cleared roots were rinsed for 3 min in 1% HCL solution then stained with Trypan Blue at 0.05% (w/v) for 20 minutes at 194 °F (90 °C). Stained root samples were then destained with lactoglycerol for 24 hr (Brundrett et al. 1984). The frequency of AM colonization for each plot was estimated using the gridline intersect method (Giovannetti and Mosse 1980). The percentage of mycorrhizal root colonization was calculated as the number of intersects in which AM fungal structures were present divided by the total number of intersects examined. The mean AM colonization rate for each plot was based on the average of three sets of observations for each 0.05 oz (1.50 g) root sample.

On November 5, 2013, 20 seedlings were lifted from 4 to 5 areas of each plot and placed in a cooler, where they were maintained at 40 °F (4 °C) until processed. For each plot, 10 seedlings with less than 10 percent foliar damage caused by Phomopsis blight were measured for height, root-collar diameter, and shoot and root fresh and dry weights. A single 0.035 oz (1.000 g) composite root subsample was removed from the 10-seedling sample to determine the AM infection rate; the remaining roots were dried for 48 hours at 176 °F (80 °C). The average root dry weights were based on the combined dry weight of the 10 seedling roots for each plot plus the estimated dry weight of the root subsample. The dry weight of each root subsample was estimated using the fresh weight to dry weight ratio of the root sample for each plot.

Root samples for AM assessments were cleared and stained using the same process as described previously. Because of difficulties in reading roots at the 12x magnification level used for the gridline intersect method, final readings were made using a slide intersect method (McGonigle et al. 1990). Ten 0.59-in (1.50-cm) root segments were placed lengthwise on a slide in lactophenol with a cover slip and sealed with clear nail polish. Three slides were prepared per root sample. A compound microscope at 200x magnification with a hairline graticule was used to make 4 passes across each slide until 150 intersections were examined for AM structures for an estimated percentage of root lengths colonized by AM fungi.

Container Study

A companion container study was initiated in a growth chamber on November 2, 2012. The container study was established as a 2 by 4 factorial design, replicated 4 times, with 2 cover crop treatments (with and without winter rye) and 4 AM treatments. The same 4 AM treatments used in the field study were applied at the same rates, with the liquid and granular products applied at 1,080 AM propagules/ft^2 (11,613 propagules/m^2) surface area and the seed treatment applied at 108 propagules/seedling (5 seedlings/container).

Soil for the container study was collected from the fumigated field used for the study at the Augusta Forest Center Nursery. Soil was put through a soil sieve No. 10 with 0.078 in (1.981 mm) openings to break up clods. Soil for each container was sterilized individually by adding 100 ml H_2O to 88.2 oz (2,500.0 g) of soil (moisture content of 8.8 percent) and microwaving for 8 min (Ferriss 1984). The microwaved soil reached temperatures of approximately 200.0 °F (93.4 °C), and the soil was allowed to cool for 24 hr before the addition of AM treatments. Each 6.0-in-deep (15.2-cm-deep) container (28.2 in^2 [182.3 cm^2] surface area) was filled with the 88.2 oz (2,500.0 g) of soil. The granular and liquid AM treatments were applied at approximately 212 AM propagules/container by mixing the treatments into the sterilized bag of soil before placing the treated soil in the container. The seed treatment was applied at 108 AM propagules/seedling by mixing 0.019 oz (0.560 ml) with 168 seeds and sowing 21 seeds/container, which was later thinned to 5 seedlings/container. Winter rye was sown at a rate of 0.007 oz (0.220 g)/container and sterilized vermiculite was then placed on top of the seeds at a depth of 0.39 in (1.00 cm). The maximum and minimum daily temperatures maintained in the growth chamber during the study were designed to mirror the seasonal pattern at the Augusta Forest Center Nursery (figure 2). Glyphosate was applied by a brush to the winter rye just before seedlings began to emerge on March 24, 2013. Nitrogen (NH_4NO_3) was applied at 0.018 oz/ft^2 (5.493 g/m^2) on July 8, July 29, August 19, and September 13. The last fertilization was applied on October 29, 2013, at 0.016 oz/ft^2 (4.882 g/m^2).

On December 9, 2013, seedlings were removed from containers by soaking them in water and gently washing soil from the root systems. Seedling height, root-collar diameter, and shoot and root fresh and dry weights were determined as previously described for seedlings in the field study. Methods for subsampling roots and determining the AM infection rate were also the same as described for the field study.

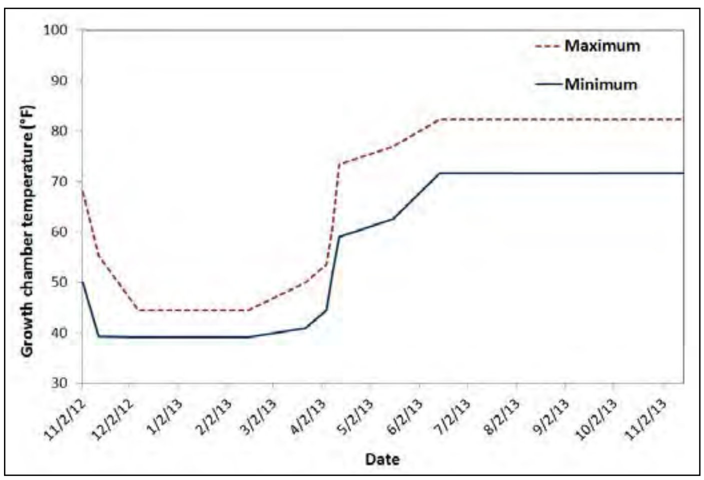


Figure 2. Minimum and maximum temperatures in growth chamber for container study.

Statistical Analyses

All data were evaluated for normality using the Shapiro-Wilk test and for homogeneity of variances using Levene's test (Systat 13, Systat Software, Inc., Chicago, IL). All data, except the AM root colonization data in the container study, were statistically analyzed by ANOVA, using the PROC GLM procedure of SAS software (SAS Institute, Inc., Cary, NC). Mean separation was performed by Tukey's HSD test. Data from the field study were analyzed as a randomized complete block design, while the container data was analyzed as a 2 by 4 factorial completely randomized design. The percentage of AM root colonization in the container study was transformed by arcsine (sqrt(X)) before analysis, but this transformation failed to provide equal variances among the mycorrhizal treatments. The data for the percentage of AM root colonization for treatment and cover crop effects were subsequently analyzed by nonparametric statistics using the Kruskal-Wallis test, and mean separation was performed by the Dwass-Steel-Chritchlow-Fligner Test for all pairwise comparisons (Systat 13, Systat Software, Inc., Chicago, IL).

Results

Field Study

The germination rate of the eastern redcedar was approximately 46 percent, 4.6 times greater than expected; therefore, the inoculation rate per seedling was actually 23 propagules/seedling. AM root length colonization 8 weeks after emergence was extremely low (0–0.83 percent), with no significant differences among treatments. By the November sampling, 23 to 54 percent root colonization by AM fungi occurred in all treatments (table 2), but there were no differences among treatments. Similarly, final seedling morphology did not differ significantly among treatments (table 2).

Container Study

Seedling height, root-collar diameter, and dry weight were significantly affected by AM and cover crop treatments in the container study, but no interactions occurred between the treatment factors for any of the seedling parameters (table 3). Although seedling size was significantly lower for seedlings sown with winter rye, AM colonization of roots did not appear to be affected by the cover crop (table 4). Mean AM root colonization among mycorrhizal treatments ranged from 2.2 to 11.8 percent with the rye cover crop and from 2.8 to 9.7 percent with no rye cover crop. The granular formulation and the liquid formulations significantly increased AM root colonization compared to the control treatment (table 5). None of the AM treatments significantly affected seedling growth compared with the control. Seedlings in the AM seed treatment had increased shoot growth compared with those in the granular or liquid treatments, although AM root colonization was not greater in the seed treatment compared with the control (table 5).

Table 2. Morphology and arbuscular mycorrhizal (AM) colonization of seedlings in the field study, November 5, 2013.[1]

MycoApply® treatment	RCD (mm)	Height (mm)	Shoot dry weight (g)	Root dry weight (g)	Percent AM colonization[2]
Granular	3.00 a	190.38 a	1.96 a	0.48 a	54.0 a
Liquid	2.79 a	163.25 a	1.42 a	0.43 a	38.0 a
Seed treat	2.69 a	154.63 a	1.35 a	0.39 a	23.2 a
Control	2.73 a	181.75 a	1.45 a	0.44 a	30.3 a

RCD = root-collar diameter.

[1] Means within columns followed by the same letter are not significantly different ($p \leq 0.05$) according to Tukey's studentized range test.

[2] Percent root length colonized by AM fungi.

Table 3. Results of statistical analyses (p-values) of arbuscular mycorrhizal (AM) treatments and cover crop and their interactions on eastern redcedar morphology and root colonization in the container study.[1]

Source of variation	RCD	Height	Shoot dry weight	Root dry weight	AM colonization
AM treatment	0.008	0.007	0.020	0.205	0.0101
Cover crop (CC)	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0642
AM x CC	0.792	0.883	0.868	0.512	—

RCD = root-collar diameter.

[1] All variables analyzed by analysis of variance, except the AM colonization, which was analyzed by the nonparametric Kruskal-Wallis test.

Table 4. Morphology and arbuscular mycorrhizal (AM) root colonization of seedlings in the container study as affected by cover crop treatment after 7 months.[1]

Cover crop	RCD (mm)	Height (mm)	Shoot dry weight (g)	Root dry weight (g)	AM colonization[2, 3] (%)
Control	2.51 a	136.89 a	1.21 a	0.85 a	4.41 a
Winter rye	1.48 b	86.58 b	0.37 b	0.33 b	6.38 a

RCD = root-collar diameter.

[1] Means followed by the same letter are not significantly different ($p \leq 0.05$) according to Tukey's studentized range test.

[2] Means within columns followed by the same letter are not significantly different ($p \leq 0.05$) according to the nonparametric Kruskal-Wallis test.

[3] Percent root length colonized by AM fungi.

Table 5. Seedling morphology and arbuscular mycorrhizal (AM) colonization of seedlings with different MycoApply® formulations in the container study.

MycoApply® treatment	RCD[1] (mm)	Height[1] (mm)	Shoot dry weight[1] (g)	Root dry weight[1] (g)	AM colonization[2, 3] (%)
Granular	1.80 b	99.83 b	0.67 b	0.52 a	10.75 a
Liquid	1.84 b	108.26 ab	0.69 b	0.55 a	8.26 a
Seed treat	2.36 a	130.68 a	1.09 a	0.72 a	2.50 ab
Control	1.97 ab	108.16 ab	0.71 ab	0.59 a	0.17 b

RCD = root collar diameter.

[1] Means within columns followed by the same letter are not significantly different ($p \leq 0.05$) according to Tukey's studentized range test.

[2] Means within columns followed by the same letter are not significantly different ($p \leq 0.05$) according to the Dwass-Steel-Chritchlow-Fligner test.

[3] Percent root length colonized by AM fungi.

Discussion

The AM fungi in the MycoApply® Endo products did not provide a growth benefit to eastern redcedar at the rate applied in the field or in the container studies. In the field study, the colonization of less than 1 percent of roots by AM fungi of the 8-week-old seedlings not only indicated that the AM inoculation was ineffective but also that naturally occurring AM fungi were reduced by fumigation in the soil's seed germination zone. The use of a winter rye as a living mulch in the seedbeds was expected to increase the inoculum potential of the endomycorrhizae (Kabir and Koide 2002, Kormanik et al. 1980b). In both the field and container studies, any increase in AM inoculum that may have occurred from the presence of winter rye was not enough to significantly affect early root colonization. Natural AM inoculum populations in the field increased over the summer and fall, and colonized all seedlings by the time of lifting, including those in the control treatments, and did not differ among treatments. This recolonization by AM fungi after fumigation is common, as viable AM fungi can remain in the soil profile outside the effective fumigation zone (An et al. 1990, Barnhill 1981, Snyder and Davey 1986). The problem with late AM root colonization is that it can be unevenly distributed within root systems and among seedlings, and many seedlings may remain stunted for a considerable time well into the growing season (Snyder and Davey 1986, South 1977).

The only mycorrhizal treatment that appeared to affect seedling growth was the seed treatment in the container study. The lack of a corresponding increase in AM root colonization indicates that AM fungi were not the cause for the increased seedling growth. This unexpected result suggests that the seed treatment may have contained something besides AM fungi that could stimulate shoot growth. The only other growth response was the smaller seedlings in the winter rye treatment, which was likely due to an inhibitory effect from the rye residue decomposing during germination and early seedling growth (Bonanomi et al. 2011).

The container studies demonstrated that at least one of the AM species in the MycoApply® Endo products can colonize eastern redcedar (figure 3), but it is unclear if this species can provide a benefit to the seedling. The granular formulation and the liquid formulation resulted in significant root colonization by AM, but the level of colonization was below 11 percent.

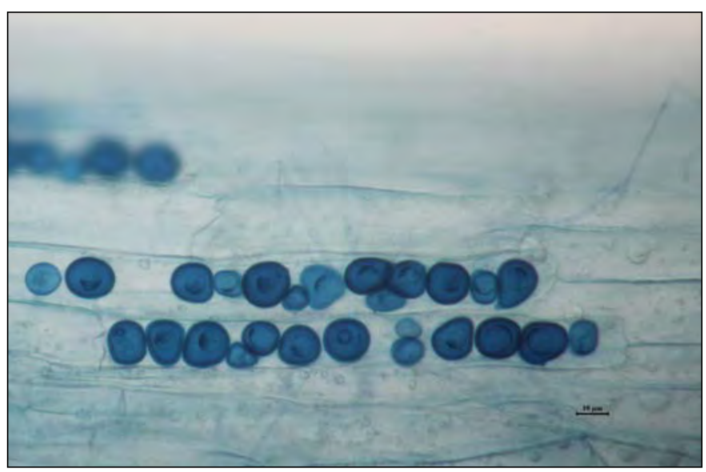


Figure 3. Arbuscular mycorrhizae roots from containerized eastern redcedar inoculated with MycoApply® granular formulation study. (Photo by Michelle Cram, 2014)

The lack of a growth response associated with AM treatments in these studies was most likely due to the low root colonization rate by the AM fungi. Other studies using similar commercial MycoApply® products applied to other host species have had better AM root colonization and significant seedling growth responses, but some key differences existed in application methods or AM fungi species used, which may affect the results. The application of an AM fungus to incense-cedar (*Calocedrus decurrens* Torr.) in an Oregon nursery used the same rate of application as in our study, but only one AM species (*Rhizophagus. intraradices*) was present (Amaranthus and Steinfeld 2005). By using a single, effective AM species, the application rate was, in effect, 4 times our application rate of the same species. In another study, the same MycoApply® Endo product containing a single AM species was used on sweetgum (*Liquidambar styraciflua* L.), but the application was applied directly to the roots of 8-day-old germinating seedlings, resulting in a high root colonization rate after 8 and 14 weeks (Corkidi et al. 2005).

The application rate of AM propagules in the field study was lower on a per-seedling basis than intended because of a higher germination rate, but not on an area basis. The lack of a seedling growth response to the MycoApply® Endo liquid and granular formulations in the container study suggests that the field results would probably not have been different even if the germination rate had resulted in the expected 10.0 seedlings/ft^2 (107.6/m^2). Given that the AM treatments were quite expensive, the use of a higher application rate would most likely be cost prohibitive at most nurseries. One way to increase AM product effectiveness could be to manipulate the application method and maximize seedling root contact with the inoculant. Application of MycoApply® on sweetgum by Corkidi et al. (2005) directly to the roots at 8 days produced AM colonization of 41 to 79 percent at 8 and 14 weeks, respectively. The granular and liquid formulations could be more effective by concentrating the product directly within the seed row or directly below the seed in nursery beds. Additional studies are needed to determine the AM species best suited for eastern redcedar seedlings, and to evaluate the effects of high root colonization rates from endomycorrhizal fungi.

Address correspondence to—

Michelle Cram, Plant Pathologist, U.S. Department of Agriculture, Forest Service, Forest Health Protection, 320 Green Street, Athens, GA 30602; e-mail: mcram@fs.fed.us.

Acknowledgments

The authors thank Dwight Stallard, Joshua McLaughlin, and Larry Estes for their support and assistance in the establishment and maintenance of the field study at the Augusta Forestry Center, Virginia Department of Forestry.

REFERENCES

Alguacil, M.; Caravaca, F.; Dıaz-Vivancos, P.; Hernandez, J.A.; Roldan, A. 2006. Effect of arbuscular mycorrhizae and induced drought stress on antioxidant enzyme and nitrate reductase activities in *Juniperus oxycedrus* L. grown in a composted sewage sludge-amended semi-arid soil. Plant and Soil. 279(1–2): 209–218.

Allen, M.F.; Swenson, W.; Querejeta, J.I.; Egerton-Warburton, L.M.; Treseder, K.K. 2003. Ecology of mycorrhizae: a conceptual framework for complex interactions among plants and fungi. Annual Review of Phytopathology. 41: 271–303.

Amaranthus, M.; Steinfeld, D. 2005. Arbuscular mycorrhizal inoculation following biocide treatment improves *Calocedrus decurrens* survival and growth in nursery and outplanting sites. In: Dumroese, R.K.; Riley, L.E.; Landis, T.D., tech. coords. National proceedings, forest and conservation nursery associations, 2004. Gen. Tech. Rep. RMRS-P-35. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 103–108.

An, Z.Q.; Grove, J.H.; Hendrik, J.W.; Hershman, D.E.; Henson, G.T. 1990. Vertical distribution of endogonaceous mycorrhizal fungi associated with soybean as affected by soil fumigation. Soil Biology & Biochemistry. 22(5): 715–719.

Barnhill, M.A. 1981. Endomycorrhizae in some nursery-produced trees and shrubs on a surface-mined area. Tree Planters' Notes. 32(1): 20–22.

Berch, S.M.; Deom, E.; Willingdon, T. 1991. Growth and colonization of western redcedar by vesicular-arbuscular mycorrhizae I fumigated and nonfumigated nursery beds. Tree Planters' Notes. 42(4): 14–16.

Bonanomi, G.; Incerti, G.; Barile, E.; Capodilupo, M.; Antignani, V.; Mingo, A.; Lanzotti, V.; Scala, F.; Mazzoleni, S. 2011. Phytotoxicity, not nitrogen immobilization, explains plant litter inhibitory effects: evidence from solid-state ^{13}C NMR spectroscopy. New Phytologist. 191(4): 1018–1030.

Brundrett, M.C.; Piché, Y.; Peterson, R.L. 1984. A new method for observing the morphology of vesicular-arbuscular mycorrhizae. Canada Journal of Botany. 62(10): 2128–2134.

Bryan, W.C.; Kormanik, P.P. 1977. Mycorrhizae benefit survival and growth of sweetgum seedlings in the nursery. Southern Journal of Applied Forestry. 1(1): 21–23.

Carpio, L.A.; Davies, F.T., Jr.; Arnold, M.A. 2003. Effect of commercial arbuscular mycorrhizal fungi on growth, survivability, and subsequent landscape performance of selected container grown nursery crops. Journal of Environmental Horticulture. 21(4): 190–195.

Corkidi, L.; Allen, E.B.; Merhaut, D.; Allen, J.F.; Downer, J.; Bohn, J.; Evans, M. 2005. Effectiveness of commercial mycorrhizal inoculants on the growth of *Liquidambar styraciflua* in plant nursery conditions. Journal of Environmental Horticulture. 23(2): 72–76.

Douds, D.D.; Chaney, W.R., Jr. 1982. Correlation of fungal morphology and development to host growth in a green ash mycorrhiza. New Phytologist. 92(4): 519–526.

Ferriss, R.S. 1984. Effects of microwave oven treatment on microorganisms in soil. Phytopathology. 74(1): 121–126.

Giovannetti, M.; Mosse, B. 1980. An evaluation of techniques for measuring vesicular arbuscular mycorrhizal infection in roots. New Phytologist. 84(3): 489–500.

Kabir, Z.; Koide, R.T. 2002. Effect of autumn and winter mycorrhizal cover crops on soil properties, nutrient uptake and yield of sweet corn in Pennsylvania, USA. Plant and Soil. 238(2): 205–215.

Kormanik, P.P.; Bryan, W.C.; Schultz, R.C. 1977. Influence of endomycorrhizae on growth of sweetgum seedlings from eight mother trees. Forest Science. 23(4): 500–505.

Kormanik, P.P.; Bryan, W.C.; Schultz, R.C. 1980a. Procedures and equipment for staining large numbers of plant root samples for endomycorrhizal assay. Canadian Journal of Microbiology. 26(4): 536–538.

Kormanik, P.P.; Bryan, W.C.; Schultz, R.C. 1980b. Increasing endomycorrhizal fungus inoculum in forest nursery soil with cover crops. Southern Journal of Applied Forestry. 4(3): 151–153.

Kormanik, P.P.; Schultz, R.C.; Bryan, W.C. 1982. The influence of vesicular-arbuscular mycorrhizae on the growth and development of eight hardwood tree species. Forest Science. 28(3): 531–539.

McGonigle, T.P.; Miller, M.H.; Evans, D.G.; Fairchild, G.L.; Swan, J.A. 1990. A new method which gives an objective measure of colonization of roots by vesicular-arbuscular mycorrhizal fungi. New Phytologist. 115(3): 495–501.

Meikle, T.W.; Amaranthus, M. 2008. The influence of fertilization regime and mycorrhizal inoculum on outplanting success: a field trial of containerized seedlings. Native Plants Journal. 9(2): 107–116.

Otta, J.D.; Fiedler, D.J.; Lengkeek, V.H. 1980. Effect of Benomyl on *Phomopsis juniperovora* infection of *Juniperus virginiana*. Phytopathology. 70(1): 46–50.

Redecker, D.; Schüßler, A.; Stockinger, H.; Stürmer, S.L.; Morton, J.B.; Walker, C. 2013. An evidence-based consensus for the classification of arbuscular mycorrhizal fungi (*Glomeromycota*). Mycorrhiza. 23(3): 515–531.

Schüßler, A.; Walker, C. 2010. The *Glomeromycota*: a species list with new families. Edinburgh, Scotland: The Royal Botanic Garden Edinburgh; Richmond, United Kingdom: The Royal Botanic Garden Kew; Munich, Germany: Botanische Staatssammlung Munich; Corvallis, OR: Oregon State University. http://www.amf-phylogeny.com. (24 October 2014).

Snyder, C.S.; Davey, C.B. 1986. Sweetgum seedling growth and vesicular-arbuscular mycorrhizal development as affected by soil fumigation. Soil Science Society of America Journal. 50(4): 1047–1051.

South, D. 1977. Artificial inoculation of fumigated nursery beds with endomycorrhizae. Tree Planters' Notes. 28(3): 3–5, 31.

Williams, R.J.; Hallgren, S.W.; Wilson, G.W.T.; Palmer, M.W. 2013. *Juniperus virginiana* encroachment into upland oak forests alters arbuscular mycorrhizal abundance and litter chemistry. Applied Soil Ecology. 65: 23–30.

International Forest Company: Helping People Grow Trees

Wayne Bell

Chief Operating Officer, International Forest Company, Moultrie, GA

Abstract

International Forest Company (IFCO), which started in 1971 as a forest seed company, has grown into the largest container seedling company in the United States. IFCO is one of many container seedling producers that make up more than 20 percent of the total seedling production in the Southeastern United States. Southern pine species are the predominant crop produced by IFCO. Through hard work, production efficiency, investment in great people, and proper planning, the company continues to grow today and into the future. This paper was presented at a joint meeting of the Northeast Forest and Conservation Nursery Association and Southern Forest Nursery Association (Williamsburg, VA, July 21–24, 2014).

Introduction

International Forest Company (IFCO) started in the tree seed-processing business in 1971 and developed a number of seed-processing machines and various technologies for improving seed quality and yield. IFCO's first commercial-scale nursery operation began in 1983 in Odenville, AL. At that time, Hilleshog, A.B., from Landskrona, Sweden, owned the company. Most of the infrastructure and machinery used at the first nursery was developed in Sweden (figure 1).

From that beginning, IFCO went on to operate four bareroot nurseries and three additional container operations, with a peak production of more than 140 million total seedlings annually. Seedlings were shipped throughout the Southeastern United States from Texas to Virginia. IFCO was purchased by management in 1993 and was sold to Mobley Plant Company in 2003, with the headquarters moving from Odenville, AL, to Moultrie, GA. Today, IFCO is a privately owned company and operates three container nurseries in Georgia, Louisiana, and Florida (figure 2).

IFCO has developed its own systems for seedling production, including an exclusive growing tray (figure 3), and has entered the genetic development field for the species it grows. IFCO is currently the largest producer of container tree seedlings in the United States, with a production of more than 72 million seedlings during the 2014–15 season (table 1). IFCO produces loblolly pine (*Pinus taeda* L.), longleaf pine (*P. palustris* Mill.), slash pine (*P. elliottii* Engelm.), shortleaf pine (*P. echinata* Mill.), and Virginia pine (*P. virginiana* Mill.). IFCO also produces eucalyptus species and a number of native plant species for ecological restoration.

The current total seedling production for the Southern United States is 190 million (Enebak 2012). IFCO's annual production of container seedling stock has steadily increased during the past 7 years (figure 4a) and follows the same increasing trend evident in the Southern States (figure 4b). IFCO's mission is to be the leading producer of high-end genetic seeds and container seedlings for establishing managed forests in the Southeastern United States.

Figure 1. When International Forest Company (IFCO) was first established, most of its equipment and infrastructure were from Sweden. (Photo by Wayne Bell, 1986)

Figure 2. Moultrie Nursery (Moultrie, GA) is one of three container nurseries that International Forest Company (IFCO) operates. (Photo by Wayne Bell, 2010)

Figure 3. International Forest Company's exclusive 128 tray with side air pruning. (Photo by Wayne Bell, 2010)

Table 1. IFCO production by species.

Species	Annual production (millions)
Loblolly pine	40
Longleaf pine	24
Slash pine	5
Shortleaf pine	2
Other	1

IFCO = International Forest Company.

IFCO's Decision Pyramid for Landowners

IFCO recently introduced the slogan, "Be Smart Before You Start." This concept was built around the idea that the seedling has a huge influence on what a landowner will grow in the next 20 to 100 years of a chosen rotation.

IFCO's sales team follows the steps in the company's decision pyramid (figure 5) to help landowners make the best decisions when starting to grow a forest. The foundation of the pyramid is the market in which landowners will sell their products. Timber traditionally has been the primary market in the South and still is today. The timber market includes pulpwood, chip-n-saw, sawtimber, or poles. New markets such as pine straw, hunting habitat, biomass pellets, carbon sequestration, endangered species habitat, and others are also emerging. The quality of the plant that landowners start with will significantly influence yields for these various markets.

Climate is the next building block on the decision pyramid for growing a successful forest. A landowner's climatic zone

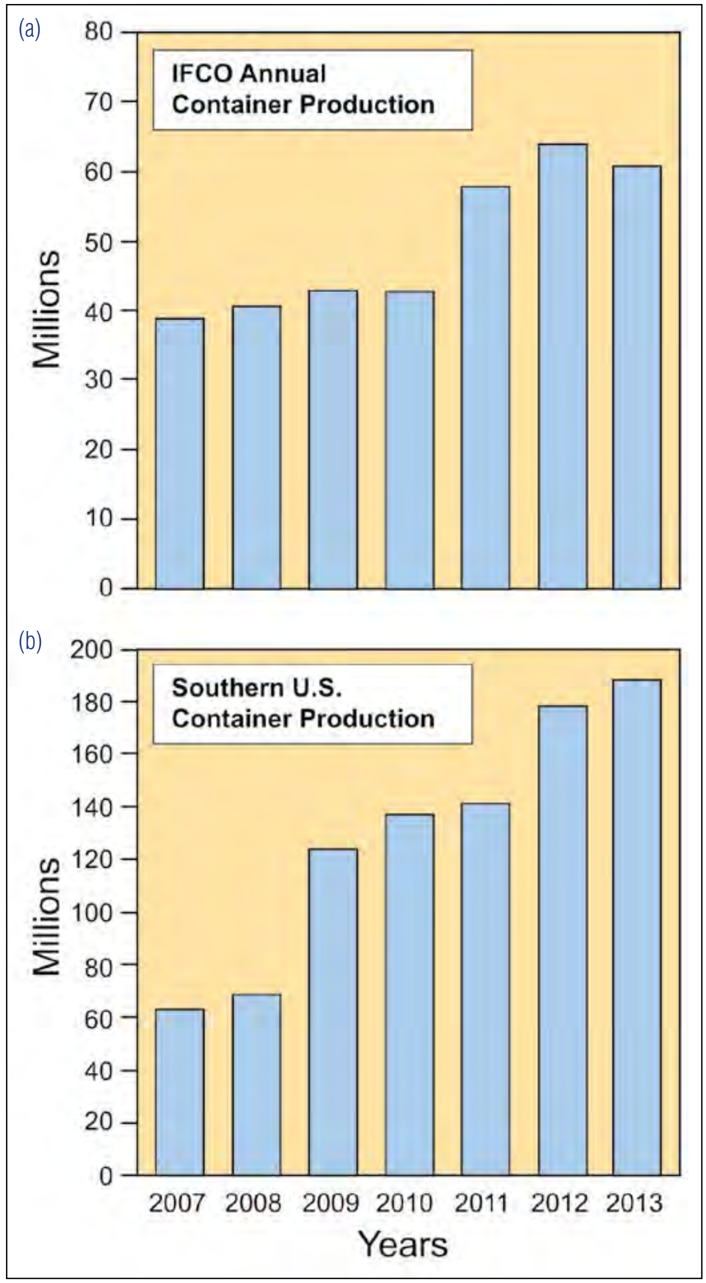


Figure 4. International Forest Company (IFCO) seedling production (a) has increased during the past several years and (b) parallels the overall seedling production in the Southern States. Source for b: Enebak (2012)

influences the choice of species and seed sources that can best flourish in particular growing conditions (e.g., temperature and length of growing season).

Soil characteristics also influence reforestation decisions. Limitations in soil nutrition, drainage, preparation, depth, and other physical and chemical characteristics can greatly influence what to plant on a given site. For example, loblolly pine requires excellent available nutrients to perform at a maximum production, and some soils are severely limited on nutrients. Longleaf pine does not grow particularly well on soils that are not well drained and may require bedding.

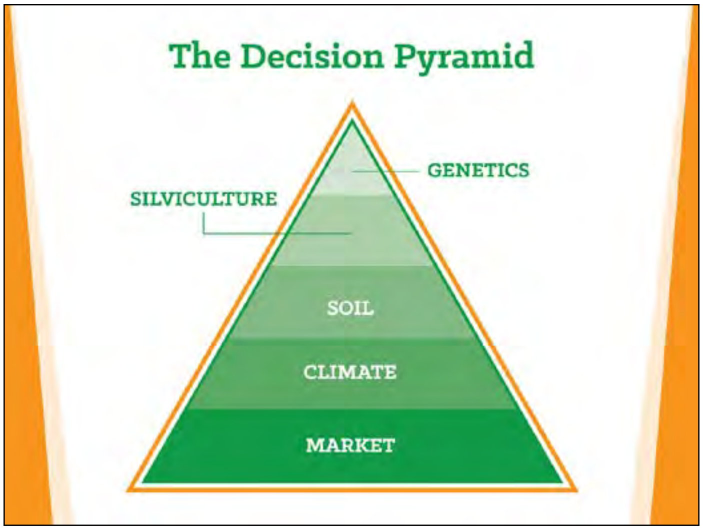


Figure 5. The decision pyramid developed by International Forest Company (IFCO) is used to help landowners with decisionmaking for growing a forest.

Silviculture is a critical factor for growing a forest. Silviculture is the art and science of growing trees and includes activities such as control of competing vegetation, fertilization, soil preparation, planting density, and bedding for excessively wet conditions. Silviculture has a huge effect on how a forest grows over time. An example of silvicultural influence is planting density; the ideal density per acre allows trees to achieve sufficient diameter growth for high-quality sawtimber.

The final component of the decision pyramid is the choice of genetics used to grow a forest. Genetic choices can affect volume growth, disease resistance, bole straightness, wood quality, and incidence of forking. All these aspects will have a significant effect on what products can be sold from the forest. All major southern pine species currently have some level of genetic improvement available.

IFCO's Future

IFCO has worked hard to increase and expand its production. The first key to increased production is hard work; nursery work is 24 hours a day, 7 days a week and requires commitment to do what it takes to deliver superior products and service. The second key is production efficiency, which is improved by continuous attention to find processes and equipment that optimize the operation. The third key is the importance of investing in great people capable of growing individually and as a team. The fourth key is planning ahead, which helps secure the proper resources and seed supply necessary for production and sales. The fifth and final key is investing time and energy into learning and applying the latest scientific knowledge, both of which are imperative to increased production. This approach led to starting a second company, International Forest Genetics and Seed Company in Moultrie, GA, in 2012, which focuses on producing seed for IFCO, with the possibility of outside seed sales in the future.

IFCO's latest addition is a 400-ac (162-ha) seed orchard complex in DeRidder, LA, where the top Western Gulf Tree Improvement Cooperative genetic material has been established. In January and February 2014, IFCO constructed a nursery-growing area at the orchard facility to produce 8 million seedlings and sowed the seed in April of the same year (figure 6).

As production capabilities grow and improve, company growth must also include market expansion. IFCO personnel attend and exhibit at more than 20 forestry and landowner conferences per year and stay active in professional societies and associations. Most important to the company's growth, however, is the company's policy of telling the customer what can be delivered and doing it, treating customers with respect, and helping others in the business along the way.

IFCO's distinguishing attributes are its highly efficient production of container seedlings, extensive experience with container seedling development, focus on genotype development, and its goal to be the most transparent seedling grower in the South so that all landowners gain the knowledge as soon as it is developed.

Figure 6. International Forest Company's (IFCO's) newest facility in DeRidder, LA, consists of a seed orchard complex and a container seedling growing area. (Photo by Jim Tule, 2013)

Address correspondence to—

Wayne Bell, Chief Operating Officer, International Forest Company, 1265 Georgia Highway 133 N, Moultrie, GA 31768; e-mail: wbell@internationalforest.co; phone: 229–985–0321.

REFERENCES

Enebak, S.A. 2012. 2012 nursery production report. Auburn, AL: Auburn University, Southern Forest Nursery Research Cooperative. 16 p.

A History of Container Seedling Production in the South

David B. South

Emeritus Professor, School of Forestry and Wildlife Sciences, Auburn University, AL

Abstract

For more than two centuries, tree seedlings (e.g., citrus and shade trees) have been grown in pots (often in greenhouses) in the Southern United States. Not only has the type of container changed over time (from clay pots and wooden boxes to polystyrene or plastic trays) but so has the predominant species grown. Before 1960, researchers used containers in greenhouse trials but few conducted field trials. Promising reports from field trials in Canada, however, stimulated a flurry of outplanting trials in the South in the 1960s. Annual container seedling production in the South reached 1.0 million by 1974 and 3.5 million by 1980; it now exceeds 180 million. Some beliefs about container stock have evolved over time. This article reviews some regional history related to container seedling production of *Eucalyptus*, hardwoods, and pines. This paper was presented at a joint meeting of the Northeast Forest and Conservation Nursery Association and Southern Forest Nursery Association (Williamsburg, VA, July 21–24, 2014).

Introduction

People have used seedling containers for more than 2,000 years. Some believe the Chinese were growing trees in containers in 500 B.C. or before. The earliest known greenhouse was built out of mica around 30 A.D. for the Roman Emperor Tiberius. The containers were "beds mounted on wheels," and these were rolled out on sunny days and then moved back under protection of the "specularia" during wintery days (Paris et al. 2008). Much later, the French botanist, Jules Charles, built a more advanced greenhouse in 1599 in Leiden, Holland. In the Southern United States, 13 States have used containers to grow tree seedlings in greenhouses for more than 200 years.

Containers and Greenhouses in the 18th and 19th Centuries

Wealthy individuals in the American colonies sometimes constructed a greenhouse on their property. For example, the September 1748 edition of the *South Carolina Gazette* contains a notice of a Charleston house for sale that had 2 greenhouses. In October 1789, upon the completion of a greenhouse at Mount Vernon, Mrs. Carroll (who also had a greenhouse) sent President Washington 20 pots of lemon [*Citrus* × *limon* (L.) Burm. f. (pro sp.) (*medica* × *aurantifolia*)] and orange [*Citrus* × *sinensis* (L.) Osbeck (pro sp.) [*maxima* × *reticulata*] trees, along with 5 boxes containing various greenhouse plants. In October 1804, Thomas Jefferson hired James Oldham to build a greenhouse at Monticello. Clay pots and wooden boxes were the most common containers used at that time. By the beginning of the 19th century, there was less than 0.5 ha of greenhouse floriculture in the United States (Henderson 1888).

As the U.S. population increased, the number of greenhouses increased. The 1840 Federal Census even asked nursery managers to report how much product they sold in 1839. In 1890, the Fruitland Nursery (Augusta, GA) had 0.4 ha of greenhouses and 150,000 conifers "nearly all pot grown" (Berkmans 1893). By the end of the 19th century, the Biltmore Nursery (Asheville, NC) had several greenhouses (Alexander 2007).

Containers and Greenhouses in the 20th Century

Before 1970, researchers used several containers types in their greenhouse trials, including traditional clay pots (Kozlowski 1943, Parker 1950), drinking glasses (Chapman 1941), wax milk cartons, glass "Mason" jars (Pessin 1938), foam cups (Kaufmann 1968; figure 1), buckets (Kozlowski 1943), or tin cans (Wenger 1952). In some cases, containers were made by hand using tar paper (Smith et al. 1963, Strachan 1974). After commercial manufacturing of containers began, researchers started using newer container types (e.g., Duffy 1970, Trew 1965).

Figure 1. In the 1970s, some researchers used foam cup containers to grow seedlings. (Photo by David South, 1979)

Because greenhouses were used in Canada for the production of reforestation seedlings, many assumed that greenhouses should also be used to produce container stock in the South. Some assumed the link between greenhouses and containers was so great that "strictly controlled greenhouses" would be needed to produce "tailored" seedlings for reforestation (Mann 1975). Some believed seedling quality would be increased because of the ability to apply "more sophisticated cultural treatments" (Cloud 1972). Greenhouses initially were thought to be useful in providing environmental conditions necessary for optimum germination.

Over time, it was realized that a greenhouse was not necessary for the production of container-grown seedlings in the South. In fact, some suggested that seedling quality (as indicated by secondary needles, freeze tolerance, wax thickness, root-collar diameter, or height/diameter ratio) could be increased by growing seedlings outside (Barnett 1989, Boyer and South 1984a, Mexal et al. 1979; figure 2). In one study, growing seedlings outside resulted in shorter seedlings and survival was increased by 9 percent (Retzlaff et al. 1990). Today, more than 180 million container-grown pines are grown outside (i.e., under no roof constructed of glass or plastic) in the South.

Eucalyptus Seedling Production

The genus *Eucalyptus* was introduced in California about 1853, and by 1908 at least 23 nurseries were selling *Eucalyptus* seedlings for $8 to $30 per thousand (Lull 1908). In the South, container-grown *Eucalyptus* seedlings were planted from Texas to South Carolina. In 1867, the French historian Jules Michelet sent seeds to his brother in New Orleans. The seedlings grew to a height of 7.9 m in less than 2 years (Mialaret 1871). However, a freeze (December 22, 1870) killed the trees. In 1873, two pot-grown *Eucalyptus globulus* Labill. ssp. *globulus* seedlings were planted near Clear Creek, TX (Anonymous 1874). The following year, Jno. A. Barksdale received seeds from Colonel Davis (Greenville, SC), sowed them in a box, and outplanted two seedlings near Lauren, SC (Barksdale 1876). In 1876, a South Carolina editor reported seeing a 2-year-old *Eucalyptus* (6 m tall) growing in Charleston (Aiken 1876). In Florida, *Eucalyptus* was planted on Merritt Island as early as 1878 (Zon and Briscoe 1911).

Containers were preferred to bareroot culture because *Eucalyptus* seeds are small and valuable. Seeds typically were sown in a wooden box and, after the young germinates emerged, they were repotted into 5-cm-diameter pots (figure 3) or transplanted into another box (Arbenz 1911, Zon and Briscoe 1911). Nurseries selling *Eucalyptus* seedlings in the 1880s included Reasoner Brothers in Oneco, FL, and American Exotic Nurseries at Seven Oaks near Clearwater, FL. In 1893, pot-grown *Eucalyptus* seedlings could be purchased from the Oneco Nursery for 20 cents each.

The demand for *Eucalyptus* nursery stock likely declined after freeze injury occurred on several species. The freeze of December 29, 1894, was so severe that Orlando, FL, recorded a low of -8 °C and West Palm Beach, FL, reached -4 °C. A second hard freeze occurred on February 9, 1895. These freeze events not only devastated the citrus industry, but also likely reduced the demand for *Eucalyptus* seedlings. Even so, in 1909, William Fremd grew more than 10,000

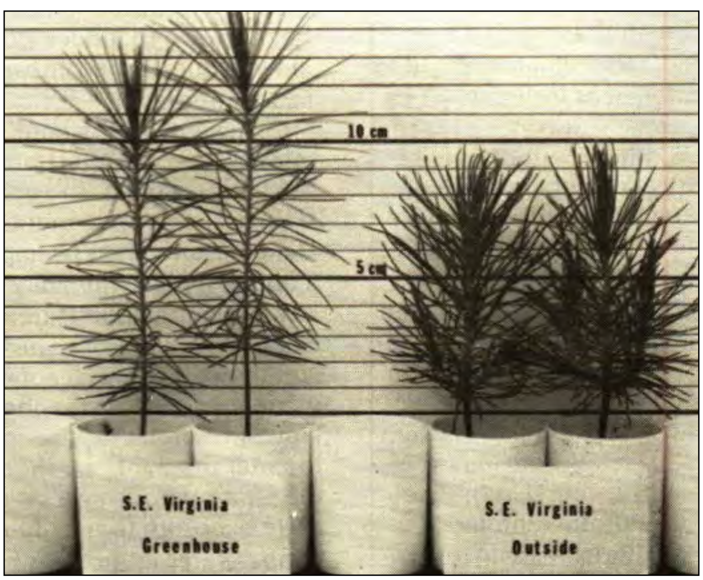


Figure 2. Loblolly pine seedlings (12 weeks from sowing) grown outside (right) had larger diameters, were shorter, and had more branches than seedlings grown inside (left) a greenhouse. (Photo from Boyer and South 1984a)

Figure 3. At the beginning of the 20th century, a person could, in 1 day, prepare soil and transplant 600 to 750 *Eucalyptus* seedlings into containers. Each wooden box contained 36 containers (5 by 5 by 20 cm). The waxed-paper containers often were not removed before planting in the field. (Photo from Toumey 1916)

Eucalyptus seedlings for use in an experimental planting for the Florida East Coast Railway. Fremd was the head gardener at the Royal Poinciana Hotel in Palm Beach, FL. The type of container used by Fremd is unknown, but Zon and Briscoe (1911: 35) indicated that "paper pots" were preferred over wooden flats. During transplanting, the paper containers were not removed, because the "moisture in the soil soon causes the paper to decay and the roots have no difficulty in piercing through it."

During the mid-1950s, several paper companies installed species trials in Florida (Mariani et al. 1978). In 1959, the Florida Division of Forestry produced about 50,000 *Eucalyptus* seedlings at the Herren Nursery (Punta Gorda, FL). The retail price of a container-grown *Eucalyptus* seedling was 15 cents while a bareroot pine seedling was 4 cents (Anonymous 1961). As a comparison, a bareroot *Eucalyptus* seedling from the Herren Nursery cost 10 cents. In the early 1970s, interest in *Eucalyptus* increased and an operational system was developed using Ray-Leach® tubes (Sampson 1974). To reduce costs, 12-week-old seedlings were extracted and then packed into cardboard boxes. Although not the first to ship seedlings in boxes, the Herren Nursery may have been the first to pack extracted seedlings into boxes.

By 1974, the cost for container *Eucalyptus* seedlings was 25 cents each and annual production at the Herren Nursery was about 305,000. At that time, George Meskimen (1974) said that "Eucalypts in Florida may already qualify as the largest containerized, machine-planted hardwood forestation effort in North America." That same year, 120,000 *Eucalyptus* seedlings were lost because of salt-water intrusion into the irrigation well (Horton 1974). Therefore, the Herren Nursery was relocated to Lake Placid, FL. Production increased and Balmer (1976) predicted Florida would produce "nearly 700,000 *Eucalyptus* in 1977 for summer planting, starting them under shade cloth." Species produced included *Eucalyptus camaldulensis* Dehnh., *E. robusta* Sm., *E. grandis* W. Hill ex Maid. *E. torelliana* F. Muell., and *E. amplifolia* Naudin. A few years later, about 200,000 seedlings were destroyed by *Cylindrocladium scoparium* (Barnard 1984). Several species trials were conducted from Texas to South Carolina (Geary 1977, Hicks et al. 1974, Kadambi and Richmond 1970, Mariani et al. 1978).

The annual demand for container-grown *Eucalyptus* in the South has increased to about 1.8 million (Enebak 2013). Depending on the level of genetic improvement, the price can vary from about 45 to 60 cents per plant (Rockwood and Peter 2014).

Hardwood Seedling Production

In 1785, George Washington sowed buckeye (*Aesculus* spp.) and oak (*Quercus* spp.) seeds in a wooden box at his greenhouse at Mount Vernon. More recently, the Arkansas Forestry Commission grew black walnut (*Juglans nigra* L.) seedlings in containers during the 1960s and 1970s (Balmer 1974; Forbes and Barnett 1974). By 1974, the Herren Nursery was growing about 300,000 "tropicals" in containers (Sampson 1974). Live oak (*Q. virginiana* Mill.), red maple (*Acer rubrum* L.), sweetgum (*Liquidambar styraciflua* L.), and sycamore (*Platanus occidentalis* L.) were also grown in containers (Anonymous 1975). In 1980, the Herren Nursery shipped more than 1 million container-grown seedlings (table 1). Farther north, sycamore and sweetgum seedlings were grown in containers in a greenhouse at North Carolina State University. In early May 1974, the 2-month-old seedlings were transported to the Federal Paperboard Nursery in Lumberton, NC, extracted, and then transplanted into nursery beds (Huang and South 1982). This transplanting might be the first incidence of plug+1 production at a forest nursery in the South.

Forestry commissions in Texas, Oklahoma, and Alabama also saw a need to produce hardwoods in containers. The Texas Forest Service Lubbock Nursery started producing pines in polystyrene trays about 1978. A greenhouse was constructed at the Lubbock Nursery to produce hardwoods for wildlife and windbreaks (Word and Fewin 1982). In 1989, the Hopper Nursery at Wallace State Community College (Hanceville, AL) was established using funds from the Alabama Forestry Commission to produce container-grown hardwoods. In 2008, they produced about 200,000 seedlings and sold them for about $1 each (Chandler 2008). In 2013, the Hopper Nursery produced about 75,000 seedlings. The Oklahoma State Nursery (Goldsby, OK) produces container-grown hardwood seedlings to the public for timber production, wildlife habitat, erosion control and windbreaks (at $4 each). The International Forest Seed Company began selling hardwood seedlings in the 1980s

Table 1. A partial list of container nurseries in the South in 1980.

State	Location	Name	Number of seedlings shipped
Arkansas	Hot Springs	Weyerhaeuser	200,000
Florida	Lake Placid	Herren	1,393,000
Georgia	Cedar Springs	Great Southern	210,000
Georgia	Savannah	Georgia Pacific	200,000*
Louisiana	Pollack	Stuart Project	533,000
North Carolina	Clayton	Griffith	700,000*
North Carolina	Trenton	Weyerhaeuser	11,000
Texas	Lubbock	West Texas	25,000
Texas	Silsbee	Kirby Forest	435,000

* Number estimated.

Sources: Anonymous (1981), Harris (1984)

(McRea 1999). They initially grew hardwoods at a density of 544/m^2 but soon realized a need to increase cell volume and reduced cell density to 244/m^2 (McRea 2005). The company recently switched from producing hardwood seedlings to producing native grasses.

Throughout the South, the price for container-grown hardwood seedlings varies greatly (table 2). This variation is due, in part, to different profit objectives among nursery administrators. In 2014, nurseries advertising container-grown hardwoods in the South were located in Alabama, Louisiana, Oklahoma, and Texas. The production of container-grown hardwoods (excluding *Eucalyptus*) across the South currently is likely less than 200,000 seedlings, which is about one-third of the production level in 1998 (McRea 1999). The decline in production may be partly due to adequate survival from bareroot hardwoods and a reduction in government subsidies.

Table 2. Selected examples of the retail price (2015) of nursery stock in the South.

Species	Bareroot (cents per tree)	Container (cents per tree)
Eucalyptus spp.	—	45 to 60
Hardwoods	21 to 90	25 to 400
Shortleaf pine	4	16.7
Longleaf pine	10	19.6
Loblolly pine—open pollinated	5.5	15.5
Loblolly pine—clone—miniplug+1	32	41

Pine Seedling Production

Pines have been grown in containers for more than three centuries. In England, John Evelyn (1664) provided brief instructions on growing pine seedlings in "earthen-pots." Although conifers were certainly grown in containers at horticultural nurseries in the South before 1900, most pine seedlings produced in the 20th century were produced in bareroot nurseries. Nonetheless, most of the container seedlings produced in forest nurseries in the South since 1960 have been pines (figure 4).

It was initially believed that greenhouses would produce higher quality seedlings (Cloud 1972, Mann 1975). Therefore, to reduce the cost of greenhouse-grown seedlings, early researchers often grew them in small containers (figure 5). For example, most of the tubes (and "blocks") tested in Louisiana were at densities greater than 1,000/m^2 (Barnett and McGilvery 1981). In Canada, a small "plantable" pine seedling could be grown in tubes in as little as 4 weeks (Saul 1968). In the South, 2- to 3-month old seedlings were initially considered old enough for planting (Barnett 1974). Some viewed growing seedlings in a greenhouse for 6 months to be a disadvantage (because it reduced the number of crops per year). Container nurseries in the South currently produce one pine crop per year. The two

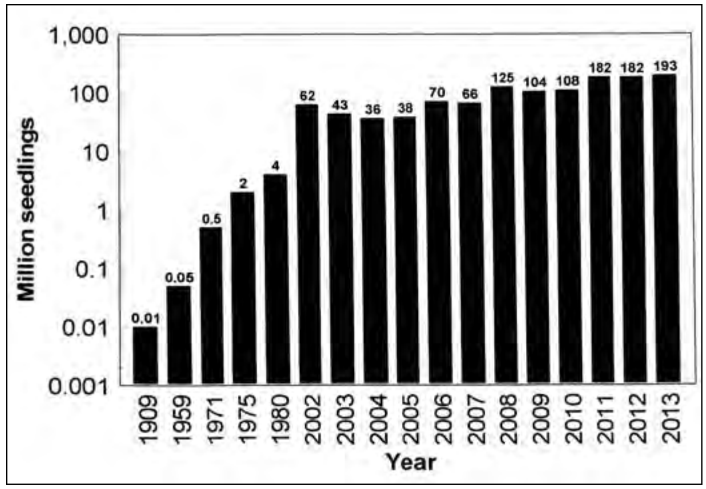


Figure 4. Estimated production of container-grown seedlings in the Southern United States. In the fall of 2013, container nursery managers produced 191 million pine (*Pinus* spp.) and more than 1.5 million *Eucalyptus* spp., 0.6 million Fraser fir (*Abies fraseri* [Pursh.] Poir.), 126,000 Atlantic white cedar (*Chamaecyparis thyoides* L. [B.S. & P.]), and more than 50,000 hardwoods. (Graph source: David South and Scott Enebak, 2014)

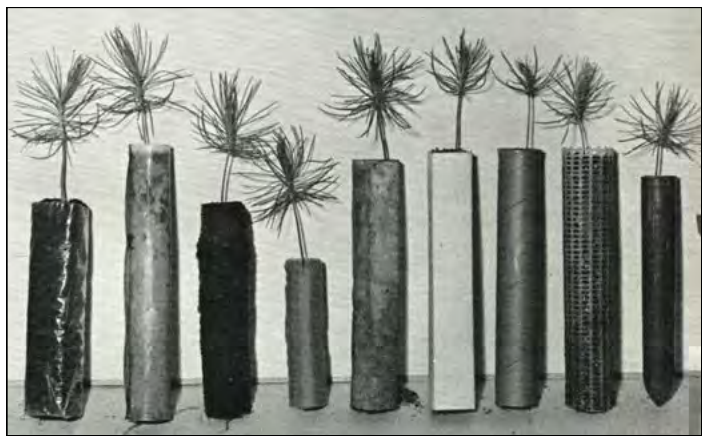


Figure 5. During the 1970s, researchers tested small containers for production of pine seedlings; some assumed seedlings would be shipped when they were just 10 weeks old. (Photo from Mann 1975)

major container species produced in the South, longleaf pine (*Pinus palustris* Mill.) and loblolly pine (*P. taeda* L.), amount to 61 and 35 percent, respectively, of the total container tree seedling production in the South (Starkey et al. 2015).

Early Field Trials With Container-Grown Pine Seedlings

Researchers were among the first to plant container-grown pines. During the early 1960s, geneticists working at the Institute of Forest Genetics (Gulfport, MS) were involved with "containerization" of longleaf pine. Traditional 1+0 bareroot seedlings were lifted (starting in December), needle-pruned to a length of 13 cm, and then transplanted into milk cartons or tar-paper pots (Smith et al. 1963). The "containerized" seedlings typically remained outside (in a concrete trough) for 1 to 4 months. This process resulted in first year survival of 95 to 97 percent (13 to 15 percent more initial survival compared with nonclipped bareroot stock), and, after two growing seasons, 94 percent of the seedlings had emerged from the grass stage.

Researchers in Florida referred to seedlings grown in “paper pots” (Hoekstra 1961) but others correctly referred to these as “fiber pots” (Vande Linde 1968). By growing seedlings in fiber pots, researchers achieved 90 percent survival of slash pine (*Pinus elliottii* Engelm. var. *elliottii*) on mine spoils east of Jacksonville (Hoekstra 1961). In 1963, West Virginia Pulp and Paper Company researchers established trials using loblolly and Virginia (*P. virginiana* Mill.) pine (Trew 1965), and later trials were established in South Carolina (Ladrach 1970a, 1970b). Seedlings in these trials were small, often less than 13 weeks from sowing. In most of these trials, the container was not removed from the seedling before outplanting.

In June 1966, LeRoy Jones (U.S. Department of Agriculture [USDA], Forest Service) established a container study at the George Walton Experimental Forest in Dooly County, GA (Balmer 1968, Jones 1967). The longleaf pine study involved testing paper and plastic tubes; in the study, tubes were planted along with the seedling.

In 1968 and 1969, researchers at Oxford, MS, established trials to compare bareroot seedlings (approximately 10 months old) with 6-week-old seedlings grown in “Walters bullet” plastic containers and outplanted (in February) with the container (McClurkin 1971). It is not surprising that the larger bareroot seedlings survived and grew better than the small container stock (Dickerson and McClurkin 1980).

In 1972, the USDA Forest Service erected two polyethylene greenhouses at Pollock, LA (Gates 1974, Slade 1972), and Dr. James Barnett subsequently tested several container types and growing systems for production of reforestation stock in the South (Barnett 1974, 1989; Barnett and McGilvray 1981). In 2009, Barnett received the Society of American Foresters’ Barrington Moore Award for his substantial advances in seed and seedling research.

The North Carolina Forest Service also constructed a research greenhouse in 1972 at the Griffith Nursery (Clayton, NC) and initiated a “Tubeling Operational Study” (Goodwin 1974). This structure perhaps was the first glass greenhouse constructed in the South for producing container-grown pine seedlings. Chris Goodwin authored one of the first manuals for producing greenhouse-grown, southern pine seedlings (Goodwin 1975) and was likely the first to set targets for stem diameter. For example, Goodwin recommended a minimum average stem diameter for loblolly pine seedlings of 1.55 mm; this average can be achieved just 8 weeks after sowing (Barnett 1989).

In 1974, Weyerhaeuser researchers compared container-grown loblolly pine seedlings grown in a greenhouse (without natural chilling) with those placed outside 13 weeks after sowing (Mexal et al. 1979) and found that seedling survival was lower when seedlings were kept in a greenhouse at temperatures of 5 °C or higher. This finding was perhaps the first in the South to question the idea that growing seedlings in a greenhouse increases seedling quality.

Following the early research described above, the number of field trials established since 1975 has increased at an exponential rate. Citations in “Google Scholar” with the exact phrase “container seedling” were not found before 1960, and only two citations occurred during the 1960s. For more recent decades, the frequency of citations observed was 56 (1970s), 106 (1980s), 231 (1990s), and 592 (2000s).

Commercial Pine Seedling Production

In 1975, at least five container manufacturing companies were in the South. Tri-State Mill Supply Company (Crossett, AR) produced polystyrene foam containers. Agritec Company, Inc. (Houston, TX) produced “test tubes” made from polyethylene, and Keyes Fibre Company (New Iberia, LA) produced a Keyes Peat Stick®. Container producers in Florida included Better Plastics (Kissimmee, FL) and Green Thumb Products (Apopka, FL). By 1980, at least nine nurseries were producing container-grown seedlings (table 1). Now more than 180 million containers are produced each year in the South (Harper et al. 2013).

The following list describes some early leaders in production of southern pine container stock.

- In 1973, the Herren Nursery in Florida was converted to a container nursery. Container-grown seedlings of south Florida slash pine (*Pinus elliottii* var. *densa*) were sold to the public for 25 cents each (Anonymous 1975). A few years later (1977), the container nursery was moved from Punta Gorda to Lake Placid.
- In Texas, Kirby Forest Industries began growing container-grown seedlings (in lath-houses) in 1973. By 1980, it was the fourth largest container facility (for reforestation) in the South (table 1). Its goal was to increase the survival of pine seedlings planted on wet, flat sites (Abbott 1982).
- Georgia Pacific constructed a shade house for the production of container seedlings near Savannah, GA. The annual production at this facility in 1975 may have been 200,000 seedlings (Balmer 1974).

- The "Plant-a-plug" company (Crossett, AR) was one of the first nurseries to contract-grow container-grown seedlings due, in part, to a local source of containers. Perhaps 560,000 pine seedlings were grown in polystyrene containers in 1975 (Balmer 1974). Seedlings were grown either outside under a shade cloth (for summer production) or inside a polyfilm greenhouse for winter production (Mason 1974). This nursery did not last very long.
- The North Carolina Forest Service turned its research greenhouse into a production nursery around 1976 (Harris 1982). By 1984, the Griffith Nursery was producing about 900,000 seedlings per year (Harris 1984). A hailstorm unfortunately damaged the greenhouse and broke many of the glass panes. Not long afterward, this facility closed.
- The Texas Forest Service began producing pines in polystyrene trays around 1978 when a greenhouse was constructed at Lubbock to produce conifers for use in windbreaks (Word and Fewin 1982). The windbreak species included ponderosa pine (*Pinus ponderosa* var. *ponderosa*) and Austrian pine (*P. nigra*). Seedlings were 18 months old at the time of distribution in March (winter crop). Both seedlings and containers were transported to outplanting sites. In 1982, the price charged to the landowner was about $1 per seedling. This facility is still in operation and currently sells container-grown pine seedlings for $2 per seedling.
- The South Carolina Forestry Commission started a container seedling program in 1983. A greenhouse was used to produce a fall crop of seedlings (sown in November) while a crop sown in April was grown outdoors in a slat house (Chilcutt 1988). Production at this facility was about 500,000 seedlings per year. This facility closed and now container-grown seedlings are produced at the Taylor Nursery in Trenton, SC.
- The International Forest Tree Seed Company (now International Forest Company) was (and continues to be) the leader in commercial production of container seedlings in the South. A container nursery was established at Odenville, AL, in 1983. The nursery manager, Wayne Bell, realized that container seedlings could be grown outdoors and that heating or cooling a greenhouse added to the cost of seedling production. At that time, it was also recognized that seedlings no longer needed to be kept small (South et al. 1994); the common container tray at Odenville had a density of 526 cells/m^2 and the annual production capacity was about 6 million. This facility closed in 2008, and a larger one is currently operational at Moultrie, GA.
    - Initially seedlings were shipped to the field in containers but returning the empty containers to the nursery was a problem. The decision was soon made to extract seedlings at the nursery and to pack seedlings in cardboard boxes. Packing seedlings not only reduced the loss of containers and eliminated the cost of shipping containers back to the nursery, but it also reduced the cost of shipping seedlings to the field. In the early 1990s, the Odenville nursery also produced rooted cuttings of loblolly pine in a glasshouse for that purpose. At that time, the total cost of producing rooted cuttings exceeded 15 cents per cutting.
    - Since the Odenville nursery opened, Bell has become "the leader" in the container business. For example, his company produced about 5 million container seedlings in 1985 and about 25 million in 2008. In 2014, the nursery at Moultrie, GA, produced more than 70 million container-grown seedlings, making it the largest container-tree nursery in the South.

Advantages and Disadvantages of Container-Grown Seedlings

For some tree genera (e.g. *Eucalyptus*), the advantages of container-grown seedlings are obvious, and few (if any) bareroot seedlings are produced. By contrast, for some hardwood species, the advantages of planting bareroot stock overshadow the disadvantages. The following section highlights some advantages and disadvantages of using container stock in the South.

Extending the Transplanting Season

An advantage of container seedlings is that when soil moisture is adequate, seedlings may be planted outside the traditional 3-month transplanting season for bareroot pines (December through March). During the early days, emphasis was placed on extending the season into the spring (i.e., before the longest day of the year) and summer (Aycock 1974, South and Barnett 1986). Over time, the risk of freeze injury associated with holding stock in the nursery during December and January (Grossnickle and South 2014, Hunt 1980, Tinus et al. 2002) resulted in a shift of the preferred season for planting containers to September, October, and November assuming soil moisture is adequate (Larson 2002, South et al. 1994).

Seed Efficiency

Before 1985, sowing more than one seed per cell was a common practice at container nurseries. When seed had a low value, and when greenhouse managers wanted to minimize the number of empty cells, two or more seeds were often sown in each cell. In addition, because containers often were shipped out to the field, the desire to have each cell filled was higher than when seedlings were extracted at the nursery. The British Columbia Ministry of Forests recommended sowing two or three seeds per cell when the germination percentage was 85 or 75 percent, respectively (South and Young 1995).

Today, one pine seed is typically sown per cell in the South. Emphasis has switched from calculating the optimum number of seeds per cell (Pepper and Barnett 1981) to either purchasing high-germination seed or improving germination with processing techniques. For some seed lots, treating seed before sowing can increase germination to greater than 90 percent (Barnett 2002). For organizations managing container and bareroot nurseries, a simple solution is to send the highest germ seed to the container nursery and the remaining lots to the bareroot nursery. This approach allows for single sowing and minimizes thinning and transplanting costs.

Potential for Toppling

Toppling occurs when high winds blow over young seedlings (typically less than 8 years after outplanting). Toppling is a problem with some pine species (figure 6), especially when growing on sites with high water tables or high sand content. Even with hurricanes, toppling of bareroot southern pines or slow-growing wildlings is rare (Khuder et al. 2007, Moore et al. 2008, Rosvall 1994). In a few rare cases, toppling has been reported on good sites for bareroot seedlings between the ages of 3 and 5 years (Harrington et al. 1989, Hunter and Maki 1980, Klawitter 1969) especially when the foliage was loaded with ice or snow.

Toppling of container-grown and bareroot stock has occurred in several countries (Van Eerden and Kinghorn 1978). In the South, toppling of container-grown longleaf pine was first reported following Hurricane Opal in 1991. Toppling also occurred during Hurricane Floyd in 1999 (South et al. 2001), Hurricane Lili in 2002, Hurricane Ivan in 2004, Hurricane Rita in 2005, and Hurricane Gustav in 2008 (Haywood et al. 2012). In young stands that have not yet experienced high winds, toppling of container-grown longleaf pine may be less than 2 percent (South 2011). Longleaf seedlings with no taproot (or no sinker roots), asymmetrical lateral roots, or spiraled lateral roots (at time of planting) are likely to topple in high winds (Sung et al. 2013).

Figure 6. Some pine species have an increased risk of toppling when grown in containers. (Photo by David South, 2010)

Miniplug Containers and Somatic Embryogenesis

In the Pacific Northwest, containers have been used in the production of plug+1 seedlings in bareroot seedbeds for more than three decades (Hahn 1984). The idea of using "miniplug" containers as plug+1 transplants in the West was pioneered by Weyerhaeuser (Hee et al. 1988). In the South, miniplug+1 bareroot stock became operational in 2002 when miniplugs (figure 7) were mechanically transplanted into nursery beds (Pait and Weir 2007). CellFor (Vancouver, Canada) pioneered the use of somatic embryogenesis to produce clones for nursery production (Sorensson 2006, Sutton et al. 2004).

In 2011, CellFor technology produced more than 12 million tissue-cultured miniplugs. This number included more than 7 million miniplug+1C plants (i.e., miniplugs transplanted into larger containers) and more than 4 million miniplug+1BR bareroot plants (Grossnickle 2014). Although CellFor went bankrupt in 2011, Arborgen is continuing the production of both miniplug+1BR stock and miniplug+1C stock in its Southern U.S. nurseries. For loblolly pine, miniplug+1BR and miniplug+1C stock sell for 32 and 41 cents, respectively (table 2).

Figure 7. Polystyrene tray containing 400 loblolly pine miniplugs produced from somatic embryogenesis. (Photo by David South, 2006)

Hand Planting Costs

Before operational container nurseries were established, many thought that container seedlings would cost less to plant than bareroot stock (e.g., Mann 1977). This view likely developed from an assumption that small container seedlings could be planted more quickly than bareroot seedlings. Because the size of container seedlings has increased over time, the total number of seedlings a planter can carry has decreased. Today, bulky container-grown seedlings cost more to transplant and plant than bareroot seedlings. In one survey, hand planting a container seedling cost 14 cents while the cost for planting a bareroot seedling was 11 cents (Dooly and Barlow 2013). Cost for shipping container-grown loblolly pine is about double that for bareroot stock. It may take two boxes to pack 670 container plugs, but it takes only one box for the same number of bareroot loblolly pine seedlings.

Selected Perceptions

In reviewing the history of container seedling production, I came across several statements regarding container stock. Some declarations are still valid today, but others are now questionable. The following statements (with associated publication dates) were found in the literature, but the full citation has been withheld. See if you can tell which statements have stood the test of time.

- "Since there is little likelihood of reducing reforestation cost with container-grown seedlings, there is little incentive to plant them during the dormant winter period." (1974)
- "The days of a man riding behind a tractor and hand-placing seedling in a slit will soon be gone." (1975)
- "Total time, from germination to shipping, will not be more than eight to ten weeks." (1975)
- "Because a long period is needed for roots to completely enmesh the growing medium, plugs do not appear ideal for southern conditions. Moreover, they must be handled carefully to prevent loss of soil from the roots, so they don't seem adaptable to mechanized planting." (1975)
- "To prevent cold damage, loblolly and shortleaf pines should be preconditioned or hardened off before planting in the fall. Slash and longleaf pines are relatively hardy and can withstand normal winter temperature within their geographic ranges." (1977)
- "Recent economic analyses indicate that for the same or better survivability and growth, container seedlings may be as inexpensive as bare-root seedlings." (1984)
- "When tissue culture is used, the greenhouse container nursery is certain to be intermediate between the flask and the field." (1984)
- "Loblolly pine and slash pine can be grown to plantable size in 12 to 14 weeks." (1986)
- "Most of the variations in performance are more of a reflection of cavities per unit area, or seedling density, than container per se." (1986)
- "The development of adverse root forms increases rapidly with the length of time seedlings are grown in containers. With 12- to 15-week growing cycles and removal of the seedlings from the container, there should be no problem if you are using properly designed containers." (1986)
- "If 5 to 15% of cavities contain ungerminated seeds, germinants from cavities with multiple seedlings or from germination flats should be transplanted to the empty cells." (1991)

Address correspondence to—

David South, Emeritus Professor, School of Forestry and Wildlife Sciences, Auburn University, Auburn, AL 36849; e-mail: southdb@auburn.edu.

Acknowledgments

The author thanks Steve Grossnickle (Nursery to Forest Solutions) for providing information on the production of miniplugs by CellFor and also thanks Tom Starkey and Scott Enebak (Southern Forest Nursery Management Cooperative, Auburn University, Alabama) for their comments on earlier drafts.

REFERENCES

Abbot, J.E. 1982. Operational planting of container growth slash pine on problem sites. In: Guldin, R.W.; Barnett, J.P., eds. Proceedings, southern containerized forest tree seedling conference. Gen. Tech. Rep. SO-37. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 113–116.

Aiken, D.W. 1876. The *Eucalyptus* again. The Rural Carolinian. 7(1): 49.

Alexander, B. 2007. The Biltmore nursery: a botanical legacy. Charleston, SC: Natural History Press. 189 p.

Anonymous. 1874. *Eucalyptus globulus* in Texas. California Farmer and Journal of Useful Sciences. 46(4): 27.

Anonymous. 1961. Trees available to landowners. Okeechobee News. October 13: 7.

Anonymous. 1975. Seedlings available from State nurseries. Forest Farmer. 34(5): 63–65.

Anonymous. 1981. 1981 directory of forest tree nurseries in the United States. Washington, DC: The American Association of Nurserymen: 40 p.

Arbenz, J.H. 1911. The *Eucalyptus* in Texas. Bull. No. 8. Austin, TX: Texas Department of Agriculture. 9 p.

Aycock, O. 1974. Field performance of containerized seedlings in the Southern region. In: Tinus, R.W.; Stein, W.I.; Balmer, W.E., eds. Proceedings, North American containerized forest tree seedling symposium. Great Plains Agricultural Council Pub. 68. Denver, CO: Great Plains Agricultural Council: 321–323.

Balmer, W.E. 1968. New techniques in planting. In: Bailey, F., tech. coord. Proceedings, symposium on planted southern pines. Cordele, GA: U.S. Department of Agriculture, Forest Service, State and Private Forestry: 121–129.

Balmer, W.E. 1974. Containerization in the Southeast. In: Tinus, R.W.; Stein, W.I.; Balmer, W.E., eds. Proceedings, North American containerized forest tree seedling symposium. Great Plains Agricultural Council Pub. 68. Denver, CO: Great Plains Agricultural Council. 38–41.

Balmer, W.E. 1976. Container-grown seedlings. In: Lantz, C., tech. coord. Proceedings, Southeastern Area nurserymen's conferences. Atlanta, GA: U.S. Department of Agriculture, Forest Service, State and Private Forestry, Southeastern Area: 44–49.

Barksdale, J.A. 1876. The *Eucalyptus* and the Malva. The Rural Carolinian. 7(1): 198.

Barnard, E.L. 1984. Occurrence, impact, and fungicidal control of girdling stem cankers caused by *Cylindrocladium scoparium* on *Eucalyptus* seedlings in a south Florida nursery. Plant Disease. 68(6): 471–473.

Barnett, J.P. 1974. Growing containerized southern pines. In: Tinus, R.W.; Stein, W.I.; Balmer, W.E., eds. Proceedings, North American containerized forest tree seedling symposium. Great Plains Agricultural Council Pub. 68. Denver, CO: Great Plains Agricultural Council: 124–128.

Barnett, J.P. 1989. Shading reduces growth of longleaf and loblolly pine seedlings in containers. Tree Planters' Notes. 40(1): 23–26.

Barnett, J.P. 2002. Activities that increase germination and establishment of longleaf pine seedlings. In: Barnett, J.P.; Dumroese, R.K.; Moorhead, D.J., eds. Proceedings, workshops on growing longleaf pine in containers. Gen. Tech. Rep. SRS-56. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 77–80.

Barnett, J.P.; McGilvray, J.M. 1981. Container planting systems for the South. Res. Pap. SO-167. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 18 p.

Berckmans, P.J. 1893. The Fruitland Nurseries. Proceedings, American Association of Nurserymen 18th annual meeting. Chicago, IL: Union and Advertiser press: 70.

Boyer, J.N.; South, D.B. 1984a. Forest nursery practices in the South. Southern Journal of Applied Forestry. 8: 67–75.

Boyer, J.N.; South, D.B. 1984b. A morphological comparison of greenhouse-grown loblolly pine seedlings with seedling grown outdoors. Tree Planters' Notes. 35(3): 15–18.

Chandler, N. 2008. Forestry Commission to sell trees. Cullman Times. February 12.

Chapman, A.G. 1941. Tolerance of shortleaf pine seedlings for some variations in soluble calcium and H-ion concentration. Plant Physiology. 16(2): 313–326.

Chilcutt, B. 1988. South Carolina Forestry Commission containerized seedling and rooted cuttings. In: Lantz, C. Proceedings, Southern Forest Nursery Association. Charleston, SC: Southern Forest Nursery Association: 39–41.

Cloud, M.C. 1972. A comparison of costs incurred in nursery production of improved and regular southern pine seedlings. In: Hitt, B.G., tech coord. Proceedings, Southeastern Area forest tree nurserymen's conference. Atlanta, GA: U.S. Department of Agriculture, Forest Service, State and Private Forestry. 77–82.

Dickerson, B.P.; McClurkin, D.C. 1980. A field trial of year-round planting of "bullet" seedlings. Tree Planters' Notes. 31(2): 21–22.

Dooly, E.; Barlow, R. 2013. Cost and cost trends for forestry practices in the South. Forest Landowner. 72(4): 22–28.

Duffy, P.D. 1970. Fertilizers for bullet-planted loblolly pines. Mississippi Farm Research. 33(7): 1, 5.

Enebak, S. 2013. Forest tree seedling production in the Southern United States for the 2012-2013 planting season. Tech. Note 13-01. Auburn, AL: Auburn University, Southern Forest Nursery Management Cooperative. 16 p.

Evelyn, J. 1664. Sylva; or a discourse of forest-trees and the propagation of timber. London, England: John Martyn for the Royal Society. 335 p.

Forbes, D.C.; Barnett, P.E. 1974. Containerized hardwoods: a partial summary of current work in production, establishment and cultural needs. In: Tinus, R.W.; Stein, W.I.; Balmer, W.E., eds. Proceedings, North American containerized forest tree seedling symposium. Great Plains Agricultural Council Pub. 68. Denver, CO: Great Plains Agricultural Council: 129–132.

Gates, J.E. 1974. Containerized seedlings, USFS, Stuart project. In: McConnell, J.L., tech. coord. Proceedings, southeastern nurserymen's conference. Atlanta, GA: U.S. Department of Agriculture, Forest Service, State and Private Forestry: 34–37.

Geary, T.F. 1977. Winter planting potential of four eucalypt species in south Florida. Tree Planters' Notes. 38(3): 14–17.

Goodwin, O.C. 1974. Field performance of containerized seedlings in North Carolina. In: Tinus, R.W.; Stein, W.I.; Balmer, W.E., eds. Proceedings, North American containerized forest tree seedling symposium. Great Plains Agricultural Council Pub. 68. Denver, CO: Great Plains Agricultural Council: 324–328.

Goodwin, O.C. 1975. Greenhouse container seedling production manual. For. Res. Note 19. Raleigh, NC: North Carolina Forest Service. 23 p.

Grossnickle, S. 2014. Personal communication. Sidney, British Columbia, Canada: Nursery Specialist, Nursery to Forest Solutions.

Grossnickle, S.; South, D.B. 2014. Fall acclimation and the lift/store pathway: effect on reforestation. The Open Forest Science Journal. 7: 1–20.

Hahn, P.F. 1984. Plug+ 1 seedling production. In: Duryea, M.L.; Landis, T.D., eds. Forest nursery manual: production of bareroot seedlings. Boston, MA: Martinus Nijhoff/Dr W Junk Publishers: 165–181.

Harper, R.A.; Hernandez, G.; Arseneault, J.; Bryntesen, M.; Enebak, S.; Overton, R.P. 2013. Forest nursery seedling production in the United States—fiscal year 2012. Tree Planters' Notes. 56(2): 72–76.

Harrington, C.A.; Brissette, J.C.; Carlson, W.C. 1989. Root system structure in planted and seeded loblolly and shortleaf pine. Forest Science. 35: 469–480.

Harris, H.G. 1982. Bare root versus containerized seedlings: a comparison of production problems and methods. In: Guldin, R.W.; Barnett, J.P., eds. Proceedings, Southern containerized forest tree seedling conference. Gen. Tech. Rep. SO-37. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 77–80.

Harris, H.G. 1984. The North Carolina Division of Forest Resources regeneration program. In: Lantz, C.W., tech. coord. Proceedings, Southern nursery conferences. Atlanta, GA: U.S. Department of Agriculture, Forest Service, Southern Region: 204–208.

Haywood, J.D.; Sung, S.J.S.; Sword Sayer, M.A. 2012. Copper root pruning and container cavity size influence longleaf pine growth through five growing seasons. Southern Journal of Applied Forestry. 36(3): 146–151.

Hee, S.M.; Stevens, T.S.; Walch, D.C. 1988. Production aspects of mini-plug transplants. In: Landis, T.D., tech. coord. Proceedings, combined meeting of the Western Forest Nursery Associations. Gen. Tech. Rep. RM-167. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 168–171.

Henderson, F. 1888. Floriculture in the United States. Garden and Forest. 1(1): 2–3.

Hicks, R.R.; Adekiya, F.Y.; Somber, S.I. 1974. Tubeling propagation of *Eucalyptus* appears successful in Texas test. Tree Planters' Notes. 25(1): 27–28.

Hoekstra, P.E. 1961. Tree-raising succeeds on barren sand tracts. Tree Planters' Notes. 48: 11–12.

Horton, A. 1974. Salt water intrusion results in relocation of nursery. Sarasota Herald-Tribune. August 6: 3-B.

Huang, B.K.; South, D.B. 1982. Integrated system approach to containerized seedling production and automated transplanting. In: Guldin, R.W.; Barnett, J.P., eds. Proceedings, Southern containerized forest tree seedling conference. Gen. Tech. Rep. SO-37. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 101–107.

Hunt, R. 1980. Bareroot planting of *Eucalyptus*. Tree Planters' Notes. 31(4): 20–22.

Hunter, S.C.; Maki, T.E. 1980. The effects of root-curling on loblolly pine. Southern Journal of Applied Forestry. 4: 45–49.

Jones, L. 1967. Tubed seedlings. Forest Farmer. 26(September): 10–11, 18.

Kadambi, K.; Richmond, G. 1970. Experimental planting of *Eucalyptus* in the Rio Grande Valley, Texas. Texas Forestry Paper No. 5. Nacogdoches, TX: Stephen F. Austin State University, School of Forestry. 4 p.

Kaufmann, M.R. 1968. Water relations of pine seedlings in relation to root and shoot growth. Plant physiology. 43(2): 281–288.

Khuder, H.; Stokes, A.; Danjon, F.; Gouskou, K.; Lagane, F. 2007. Is it possible to manipulate root anchorage in young trees? Plant and Soil. 294(1–2): 87–102.

Klawitter, R.A. 1969. Wind damages improperly planted slash pine. Southern Lumberman. 218(2709): 24.

Kozlowski, T.T. 1943. Transpiration rates of some forest tree species during the dormant season. Plant Physiology. 18(2): 252–260.

Ladrach, W.E. 1970a. Progress report on 1969 containerized seedling tests. Research Report 48. Winnsboro, SC: Westvaco Timberlands Division, Winnsboro Research Center. 12 p.

Ladrach, W.E. 1970b. Progress report on 1970 containerized seedling tests. Research Report 49. Winnsboro, SC: Westvaco Timberlands Division, Winnsboro Research Center. 9 p.

Larson, D.R. 2002. Field planting containerized longleaf pine seedlings. In: Barnett, J.P.; Dumroese, R.K.; Moorhead, D.J., eds. Proceedings, workshops on growing longleaf pine in containers—1999 and 2001. Gen. Tech. Rep. SRS-56. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 62–63.

Lull, G.B. 1908. A handbook for *Eucalyptus* planters. Circular #2. Sacramento, CA: California, State Board of Forestry. 48 p.

Mann, W.F. 1975. Progress and trends in artificial regeneration. Forest Farmer. 34(5): 48–50.

Mann, W.F. 1977. Status and outlook of containerization in the South. Journal of Forestry. 75(9): 579–581.

Mariani, E.O.; Wood, W.A.; Kouchoukos, P.C.; Minton, M.B. 1978. The *Eucalyptus* energy farm: feasibility study and demonstration phase 1: site and species selection. USDOE-HCP/T2557-01. Springfield, VA: U.S. Department of Commerce, National Technical Information Service. 304 p.

Mason, J. 1974. Plant-a-plugs systems. In: McConnell, J.L., tech. coord. Proceedings, Southeastern nurserymen's conference. Atlanta, GA: U.S. Department of Agriculture, Forest Service, State and Private Forestry: 48–50.

McClurkin, D.C. 1971. Containerized pines for eroded watersheds. Journal of Soil and Water Conservation. 26(1): 25–26.

McRea, J. 1999. Commercial containerized hardwood seedling production in the Southern USA. In: Landis, T.D.; Barnett, J.P., tech. coords. National proceedings, forest and conservation nursery associations. Gen. Tech. Rep. SRS-25. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 35–38.

McRea, J. 2005. Container hardwood seedling production. In: Dumroese, R.K.; Riley, L.E.; Landis, T.D., tech coords. National proceedings, forest and conservation nursery associations. Proceedings RMRS-P-35. Medford, OR: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 26–27.

Meskimen, G. 1974. Breaking the size barrier in containerization: "washed" *Eucalyptus* seedlings. In: Tinus, R.W.; Stein, W.I.; Balmer, W.E., eds. Proceedings, North American containerized forest tree seedling symposium. Great Plains Agricultural Council Pub. 68. Denver, CO: Great Plains Agricultural Council: 200–204.

Mexal, J.G.; Timmis, R.; Morris, W.G. 1979. Cold-hardiness of containerized loblolly pine seedlings: its effect on field survival and growth. Southern Journal of Applied Forestry. 3(1): 15–19.

Mialaret, A. 1871. Letter to the editor. Daily Picayune. December 17, 1871: 14.

Moore, J.R.; Tombleson, J.D.; Turner, J.A.; Van der Colff, M. 2008. Wind effects on juvenile trees: a review with special reference to toppling of radiata pine growing in New Zealand. Forestry. 81(3): 377–387.

Pait, J.; Weir, R. 2007. Varietal forestry: technology and benefits. http://c.ymcdn.com/sites/www.forestlandowners.com/resource/resmgr/imported/PROC1_Normanly_Brian_presentation_part_1.pdf. (October 2014).

Paris, H.S.; Janick, J.; Pitrat, M. 2008. What the Roman emperor Tiberius grew in his greenhouses. In: Pitrat, M., ed. Proceedings, IXth EUCARPIA meeting on genetics and breeding of *Cucurbitaceae*. Avignon, France: French National Institute for Agricultural Research. 33–42.

Parker, J. 1950. The effects of flooding on the transpiration and survival of some southeastern forest tree species. Plant Physiology. 25(3): 453–460.

Pepper, W.D.; Barnett, J.P. 1981. Predicting seed germination and seedling establishment in containers. Canadian Journal of Forest Research. 11(3): 677–681.

Pessin, L.J. 1938. Effect of soil moisture on the rate of growth of longleaf and slash pine seedlings. Plant Physiology. 13: 179–189.

Retzlaff, W.A.; Miller, A.E.; Allen, R.M. 1990. Comparison of container-grown *Pinus taeda* L. seedlings raised outdoors and in a growth chamber in sunlight. New Forests. 4(3): 223–230.

Rockwood, D.L.; Peter, G.F. 2014. *Eucalyptus* and *Corymbia* species for pulpwood, mulchwood, energywood, windbreaks, and/or phytomediation. Gainesville, FL: University of Florida/IFAS Extension. https://edis.ifas.ufl.edu/pdffiles/FR/FR01300.pdf. (February 2015).

Rosvall, O. 1994. Stability in lodgepole pine and resistance to wind and snow loads. Report 2. Uppsala, Sweden: The Forestry Research Institute of Sweden. 47 p.

Sampson, O. 1974. Growing containerized *Eucalyptus* in south Florida. In: Tinus, R.W.; Stein, W.I.; Balmer, W.E., eds. Proceedings, North American containerized forest tree seedling symposium. Great Plains Agricultural Council Pub. 68. Denver, CO: Great Plains Agricultural Council: 330–333.

Saul, G.H. 1968. Copper safely controls roots of tubed seedlings. Tree Planters' Notes. 19(1): 7–9.

Slade, L. 1972. Containerized seedling program—where do we stand? In: Hitt, B.G., tech. coord. Proceedings, Southeastern Area forest tree nurserymen's conference. Atlanta, GA: U.S. Department of Agriculture, Forest Service, State and Private Forestry, Southeastern Area: 83.

Smith, L.F.; Snyder, E.B.; Scarbrough, N.M. 1963. Care of pine seedlings used in breeding at Institute of Forest Genetics. Research Note SO-2. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 4 p.

Sorensson, C. 2006. Varietal pines boom in the US South. New Zealand Journal of Forestry. 51(2): 34–40.

South, D.B. 2011. Scalping improves early growth of longleaf pine seedlings. Native Plants Journal. 12(1):18–26.

South, D.B.; Barnett, J.P. 1986. Herbicides and planting date affect early performance of container-grown and bare-root loblolly pine seedlings in Alabama. New Forests. 1(1): 17–27.

South, D.B.; Shelton, J.; Enebak, S.A. 2001. Geotropic lateral roots of container-grown longleaf pine seedlings. Native Plants Journal. 2: 126–130.

South, D.B.; Young, C. 1995. Germinant sowing in South Africa. Tree Planters' Notes. 46(1): 7–10.

South, D.B.; Zwolinski, J.B.; McRae, J.B. 1994. Influence of container size and spacing on first-year field performance of *Pinus taeda*. In: Bryson, L.J., ed. Proceedings, Southern Nurserymen's Association research conference. Atlanta, GA.: Southern Nurserymen's Association. 39: 104–107.

Starkey, T.E.; Enebak, S.A.; South, D.B. 2015. Forest seedling nursery practices in the Southern United States: container nurseries. Tree Planters' Notes. 58(1): 18–26.

Strachan, M.D. 1974. Tar paper containers. In: Tinus, R.W.; Stein, W.I.; Balmer, W.E., eds. Proceedings, North American containerized forest tree seedling symposium. Great Plains Agricultural Council Pub. 68. Denver, CO: Great Plains Agricultural Council: 209–210.

Sung, S.; Haywood, D.; Sayer, M.A. 2013. Linking seedling quality and sapling vertical stability via the root system architecture of container stock longleaf pine. http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1117316.pdf. (October 2014).

Sutton, B.C.S.; Attree, S.M.; El-Kassaby, Y.A.; Grossnickle, S.C.; Polonenko, D.R. 2004. Commercialisation of somatic embryogenesis for plantation forestry. In: Walter, C.; Carson, M.J., eds. Plantation forest biotechnology for the 21st century. Trivandrum, Kerala, India: Research Signpost: 275–301. Chapter 17.

Tinus, R.W.; Sword, M.A.; Barnett, J.P. 2002. Prevention of cold damage to container-grown longleaf pine roots. In: Barnett, J.P.; Dumroese, R.K.; Moorhead, D.J., eds. Proceedings, workshops on growing longleaf pine in containers—1999 and 2001. Gen. Tech. Rep. SRS-56. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 55–57.

Trew, I.F. 1965. Tubed and bulleted seedlings. Res. Rep. 17. Ivy, WV: West Virginia Pulp and Paper Timberlands Division, Charlottesville Research Center. 13 p.

Van Eerden, E.; Kinghorn, J.M., eds. 1978. Root form of planted trees symposium. No. 8 Joint Rep. Victoria, British Columbia, Canada: British Columbia Ministry of Forests/Canadian Forestry Service. 357 p.

Vande Linde, F. 1968. Topics relating to forest nursery practices. In: Jones, L., ed. Proceedings, Southeastern Area forest nurserymen conferences. Atlanta, GA: U.S. Department of Agriculture, Forest Service, State and Private Forestry, Southeastern Area: 39–41.

Wenger, K.F. 1952. Effect of moisture supply and soil texture on the growth of sweetgum and pine seedlings. Journal of Forestry. 50(11): 862–864.

Word, D.L.; Fewin, R.J. 1982. West Texas nursery operations. In: Brissette, J.; Lantz, C., eds. Proceedings, Southern nursery conferences. Atlanta, GA: U.S. Department of Agriculture, Forest Service, State and Private Forestry, Southeastern Area: 77–87.

Zon, R.; Briscoe, J.M. 1911. *Eucalyptus* in Florida. Bull. 87. Washington, DC: U.S. Department of Agriculture, Forest Service.

Prairie Plant Production at the Mason State Nursery, Topeka, IL

David J. Horvath

Natural Resource Site Manager, Illinois Department of Natural Resources, Mason State Nursery, Topeka, IL

Abstract

The Mason State Nursery has been producing native Illinois prairie forbs and grasses since the late 1970s. Increased demand for plant materials for restoration and governmental programs in the 1980s led the Illinois Department of Natural Resources to institute a capital expansion of the nursery program. This expansion included construction of a greenhouse facility to grow prairie plants and clean the seed from these forbs and grasses. Custom growing agreements with other agencies led to additional expansion of the greenhouse facilities to meet additional production demands. Over time, experimentation with different growing regimens and containers has resulted in current container production methods now in use at the Mason State Nursery. This paper was presented at a joint meeting of the Northeast Forest and Conservation Nursery Association and Southern Forest Nursery Association (Williamsburg, VA, July 21–24, 2014).

Introduction

During the late 1970s, the Illinois Department of Natural Resources (IDNR) began to expand its activities to include personnel and programs designed to protect and manage the prairie and other natural communities of the State. One of the more important components of this new direction was developing programs to establish prairie restorations on IDNR-owned properties. Although more than two-thirds of Illinois originally had been prairie, by the 1960s, less than 1 percent of these areas remained in native vegetation. The increasing demand for agricultural lands, coupled with the growing population of the State, resulted in the loss of more than 99 percent of the State's prairies.

In 1977, the Division of Forest Resources was approached by land managers for assistance in establishing prairie grass seed collection areas. The IDNR Nursery Program was considered for this role for several reasons: (1) land for the establishment of seed collection areas was available at the nursery, (2) an experienced workforce was located at the nursery, and (3) equipment for collection and processing was either available on site or could be located in the surrounding farm community.

While the fledgling prairie program was developing, the demand for plant materials from the two State nurseries was increasing, partly because of the Federal Conservation Reserve Program (CRP) and the Illinois Forestry Development Act (FDA). As a result of the 1985 and 1990 Farm Bills, CRP participation has resulted in 36,000 ac (14,570 ha) being designated for tree planting since 1985. The demands for planting stock generated by CRP and FDA and a shift from conifer production to hardwood production created a situation that left existing nursery facilities unable to meet production demands.

To meet this increasing demand, IDNR instituted a capital program to expand and rehabilitate the nursery facilities. In 1988, this program provided $5.8 million for nursery expansion and rehabilitation.

Nursery Expansion

Most of the expansion activity was focused at the Mason State Nursery located in Topeka and occurred from 1988 through 1998. Nursery acreage was increased from 80 to 240 ac (32 to 97 ha). Irrigated seedbed area was increased from 40 to 120 ac (8 to 23 ha). A new 46 by 80 ft (14 by 24 m) building was also constructed specifically for drying and cleaning prairie forb and grass seed. A Crippen fanning mill, brush debearder, and indent seed separator were purchased and installed in this building to increase the ability to clean and process seed.

One important capital item during this time period was the construction of a 3,000 ft^2 (279 m^2) greenhouse (figure 1). This structure was built specifically for producing prairie forb and grass plants. In developing the prairie program, it was found that many species would not produce individual plants when grown in seedbeds. A lack of individual plants created considerable problems during lifting and grading. Mold development during overwinter storage of fall-harvested bareroot prairie forbs was also a problem. The greenhouse enabled production of these prairie species as individual plants and reduced the incidence of molding when in storage.

In the early 1990s, the Illinois Department of Transportation (IDOT) entered into an intergovernmental agreement with IDNR to produce prairie plants for IDOT's use along road

Figure 1. Greenhouse built in 1991 at the Mason State Nursery. (Photo by David J. Horvath, 2014)

right-of-ways and rest areas. The agreement allowed IDOT to reimburse IDNR for prairie plants and seed that were produced. Later in the 1990s, IDNR entered into another agreement with the U.S. Department of Agriculture (USDA), Forest Service Midewin National Tallgrass Prairie (Wilmington, IL) to grow prairie plants from seed collected by USDA Forest Service staff.

To increase efficiency and meet the production demands required by the growing agreements, prairie plant production was moved from outdoor, bareroot seedbed production to all container production in the greenhouse. Because of this transition, it became apparent that one greenhouse was not enough to meet production demands and dedicated space was needed to fill and seed containers.

To meet the increased demand, workers constructed two 80 by 30 ft (24 by 9 m) polyhouses and a 40 by 25 ft (12 by 8 m) building to fill containers and store materials. A bulk soil mixer was also purchased. The original 3,000 ft^2 (279 m^2) greenhouse was capable of producing approximately 40,000 plugs using a 45-cell plastic multipot (IPL Rigipot with 7 in^3 [110 ml] volume) supplied by Stuewe and Sons, Inc. (Tangent, OR) (figure 2). With the two additional polyhouses, production was increased to more than 100,000 plugs, and the dedicated potting building increased efficiency and production flow.

Current Production System

Developing a production system and a final product that would meet customer demands proved challenging. IDOT decided on 1.0 gal (3.8 L) containers for prairie material and 2.0 and 5.0 gal (7.6 and 18.9 L) containers for trees and shrubs to allow for greater flexibility and a longer planting

Figure 2. Rigipots used for production of New England aster (*Symphyotrichum novae-angliae* [L.] G L Nesom.) at the Mason State Nursery. (Photo by David J. Horvath, 2014)

window compared with bareroot or plug material. Midewin National Tallgrass Prairie and IDNR field staff still prefer plant material grown in the 45-cell multipot.

After experimenting with different plug containers, Jiffy pellets (Jiffy J7 Forestry Peat Pellet, 36 pellets per tray; Jiffy Products of America, Inc., Lorain, OH) were chosen to germinate and grow our prairie species for transplanting into pots and for direct outplanting to the field. The Jiffy forestry pellets work well for these situations and provide the added benefit of not having to retrieve and clean the plug trays (figure 3).

The growing regimen for prairie species at Mason State Nursery starts in March or April with sowing seed into Jiffy Forestry plug and 45-cell multipot containers. Sowing is done by hand because it is the most efficient method because of

Figure 3. Jiffy pellets used for production of rough blazing star (*Liatris aspera* Michx.) at the Mason State Nursery. (Photo by David J. Horvath, 2014)

the number of species and the variation in seed size among species. Recalibrating a mechanical seeder for each species was found to be overly time-consuming.

Prairie forb and grass seed is germinated and grown until about June, at which time most species are ready to be transplanted to 1.0-gal (3.8-L) containers and moved outside for continued growth. The Jiffy Forestry pellets are used for repotting into larger containers or transplanting into the field. Usually three plugs are transplanted into each pot so, under optimum conditions, our greenhouse can grow enough plugs for 13,000 pots; actual production averages around 8,000 to 10,000 pots. Total 1.0-gal (3.8-L) container production from all houses is generally 20,000 to 30,000 pots, depending on the year and conditions. Plants produced in the 45-cell multipots can be planted at any time during the summer but are usually held and grown in the cell trays throughout the summer, allowed to go dormant, unplugged, counted, and held in cold storage for spring use. All 1.0 gal (3.8 L) and larger size containers are grown throughout the summer and then stored in cold storage (1.0 gal [3.8 L]) or cold frames (2.0 and 5.0 gal [7.6 and 18.9 L]) until spring distribution. Container and greenhouse plug production numbers for the spring of 2014 are listed in table 1. Species grown for container production at the Mason State Nursery are presented in table 2.

Address correspondence to—

David J. Horvath, Natural Resource Site Manager, Illinois Department of Natural Resources, Mason State Nursery, 17855 N. County Road 2400E, Topeka, IL 61567; e-mail: dave.horvath@illinois.gov; phone: 309–535–2185.

Table 1. Container material for distribution from Illinois' Mason State Nursery in the spring of 2014.

Plant material	Stocktype	Number distributed
Forbs and grasses	1.0 gal (3.8 L) containers	20,000
Trees and shrubs	2.0 and 5.0 gal (7.6 and 18.9 L) containers	3,000
Forbs and grasses	Plugs from 45-cell multipot	40,000

Table 2. Species grown in containers at Illinois' Mason State Nursery.

Species	Scientific name
Grasses	
Northern dropseed	*Sporobolis heterolepis*
Big bluestem	*Andropogon gerardii*
Little bluestem	*Schizachryium scoparium*
Sand love grass	*Eragrostis trichodes*
Side oats	*Boutilou acurtipendula*
Indian grass	*Sorghastrum nutans*
Forbs	
Black-eyed Susan	*Rudbeckia hirta*
Partridge pea	*Chamaecrista fasiculata*
Spike blazing star	*Liatris spicata*
Butterfly weed	*Asclepias tuberosa*
Lance leaf coreopsis	*Coreopsis lanceolata*
Lead plant	*Amorpha canescens*
Obedient plant	*Physostegia virginiana*
Smooth aster	*Aster laevis*
Purple prairie clover	*Dalea purpurea*
White prairie clover	*Dalea candida*
Purple coneflower	*Echinacea purpurea*
Stiff tickseed	*Coreopsis palmata*
Tall gayfeather	*Liatris pycnostachya*
Gray headed coneflower	*Ratibida pinnata*
Rough blazing star	*Liatris aspera*
Pale purple coneflower	*Echinacea pullida*
New England aster	*Aster novae-angliae*
Spiderwort	*Tradescantia ohiensis*
Oxeye sunflower	*Heliopsis helianthoides*
Royal catchfly	*Silene regia*
Western sunflower	*Helianthus occidentalis*
Compass plant	*Silphium laciniatum*
Rosin weed	*Silphium integrifolium*
Alum root	*Heuchera richardsonii*
Prairie dock	*Silphium terebinthinaceum*
Round headed lespedeza	*Lespedeza capitata*
Illinois mimosa	*Desmanthus illinoensis*
Indigo bush	*Amorpha fruticosa*
New Jersey tea	*Ceanothus americanus*
Wild blue iris	*Iris shrevei*
Trees	
Hackberry	*Celtis occidentalis*
Bur oak	*Quercus macrocarpa*
Shumard oak	*Quercus shumardii*
Pin oak	*Quercus palustris*
Shingle oak	*Quercus imbricaria*
Bald cypress	*Taxodium distichum*
Northern white cedar	*Thuja occidentalis*
White pine	*Pinus strobus*
Cherrybark oak	*Quercus falcata*
Norway spruce	*Picea abies*
Chinkapin oak	*Quercus muehlenbergii*
Pecan	*Carya illinoensis*

Growing Container Seedlings: Three Considerations

R. Kasten Dumroese and Thomas D. Landis

Research Plant Physiologist, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Moscow, ID; Native Plant Nursery Consultant, Medford, OR

Abstract

The science of growing reforestation and conservation plants in containers has continually evolved, and three simple observations may greatly improve seedling quality. First, retaining stock in its original container for more than one growing season should be avoided. Second, strongly taprooted species now being grown as bareroot stock may be good candidates for container production. Third, miniplug seedlings that combine growth in containers followed by bareroot culturing may be a way to improve bareroot bed density and shorten production cycles. This paper was presented at a joint meeting of the Northeast Forest and Conservation Nursery Association and Southern Forest Nursery Association (Williamsburg, VA, July 21–24, 2014).

Introduction

Seedling production in containers in the Southern United States can be traced back more than two centuries (South 2015). More recently, Balmer (1974) reported more than two dozen tree species had been grown in containers in the South by a variety of public and private nurseries, including seven species of pines (*Pinus* spp.) and six species of oaks (*Quercus* L. spp.). Within a decade, Barber (1982), as keynote speaker to the 1981 Southern Containerized Forest Tree Seedling Conference (Guilin and Barnett 1982), envisioned how container seedlings and their mechanized deployment could be used in the South to improve forest productivity, especially on harsh sites. Appreciable research and guidelines followed, especially for container pines (e.g., Barnett and Brissette 1986, Barnett and McGilvray 1997, Dumroese et al. 2009). The improvements in survival and growth of container seedlings, longleaf pine (*Pinus palustris* Mill.) in particular, fueled a large increase in container seedling production in the Southern United States (Dumroese and Barnett 2004). In 2014, the joint meeting of the Southern Forest Nursery Association and Northeast Forest and Conservation Nursery Association once again had container seedling production as its theme. For nursery managers considering adding container seedling production to their nursery operations, we offer three thoughts for consideration: (1) the problem with holdover stock, (2) the potential to grow strongly taprooted species in containers to higher quality than can be achieved by bareroot culture, and (3) the potential use of minicontainers to grow transplants for plug+1 stock types that could improve seedling quality and reduce production time.

Holdover Stock

For a variety of reasons, nursery managers often find themselves with surplus container stock at the end of the shipping season. This surplus may occur because of shifts in the market, late orders that delay sowing, inaccurate inventories, or poor outplanting conditions. Nursery managers generally have an aversion to throwing away good seedlings because it means throwing away dollars. Although it is tempting, holding stock over from one growing season to the next without either transplanting it to a larger container or growing it as plug+1 seedling is not recommended (Landis 2010). Although only a few studies in the literature address this topic, the conclusions are the same: holding stock over in the same container reduces seedling quality and can result in reduced growth after outplanting or even seedling mortality. Salonius et al. (2002) found that seedling size was significantly reduced 4 years after outplanting when three conifer species (white spruce [*Picea glauca* (Moench) Voss], red spruce [*Picea rubens* Sarg.], and eastern white pine [*Pinus strobus* L.]) were held over in their same containers (figure 1). South and Mitchell (2006) concluded that when stem diameter exceeded a critical threshold in a specific container size (root-bound index), survival of longleaf pine seedlings declined drastically (figure 2). Outplanting survival of Scots pine (*Pinus sylvestris* L.) seedlings grown too long in their containers in Sweden also declined, especially during the second season after outplanting (Josefsson 1991) (figure 3). Because most growers often use a single container type, the solution that would seem to make the most sense, especially in the Southern United States, is to transplant container stock to bareroot beds and grow them as plug+1 seedlings. Given that word of mouth is one of the best marketing tools that nursery managers have, it is unwise to sell poor-quality, held-over stock to customers.

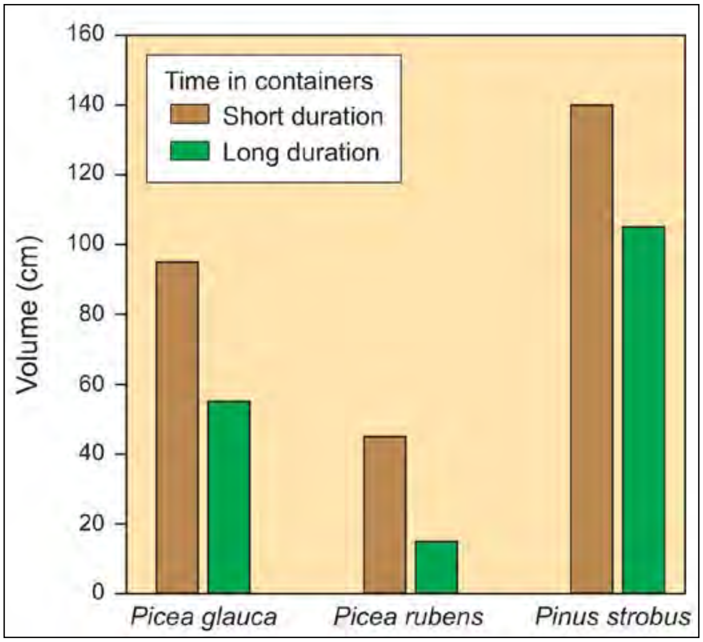


Figure 1. After 4 years on the outplanting site, white spruce (*Picea glauca*), red spruce (*P. rubens*), and eastern white pine (*Pinus strobus*) seedlings kept in their Styrofoam™ containers (170 cm^3 [10 in^3]) for the longest duration (11 months) during nursery production grew less than seedlings grown for a shorter duration (6 months). Adapted from Salonius et al. (2002).

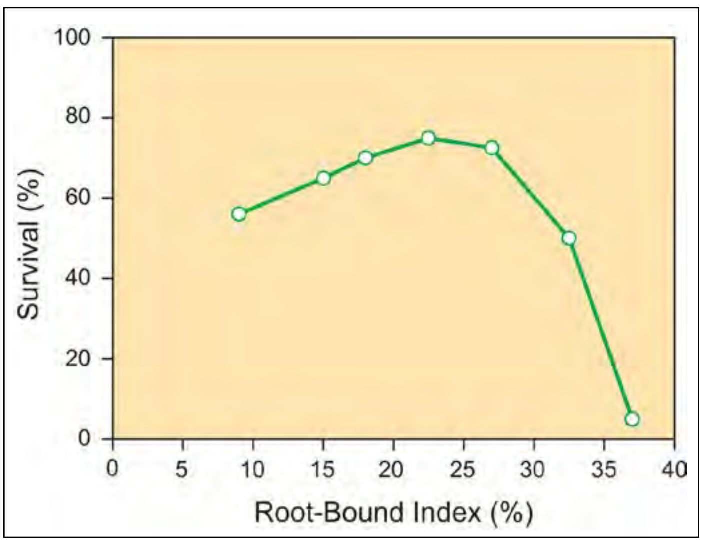


Figure 2. Longleaf pine seedlings that have a root-bound index (ratio of stem diameter to container diameter) exceeding 22 percent had reduced survival after outplanting. Adapted from South and Mitchell (2006).

Taprooted Species

A niche that container nursery managers in the South could explore is production of species with strong taproots, such as oaks and hickories (*Carya* L. spp.). One reason that container production of the strongly taprooted species longleaf pine increased dramatically during the past two decades is because seedling survival and growth exceeded that found with bareroot seedlings (South et al. 2005). It is possible that other taprooted species may respond similarly. For example, Wilson et al. (2007) found that first order lateral root (FOLR) production was much greater in container northern red oak (*Quercus rubra* L.) seedlings than in their bareroot cohorts (figure 4). FOLR proved to be a good prediction of height and diameter growth after outplanting, although not as good as that obtained by root volume (Jacobs et al. 2005). Woolery and Jacobs (2014) found that second year survival of 1-year-old container northern red oak seedlings equaled or exceeded that of 2+0 bareroot seedlings, as did relative height growth (figure 5). Taprooted species, such as hickory, that are challenging to grow as 2+0 bareroot stock (Luna et al. 2014), may respond well to container culture.

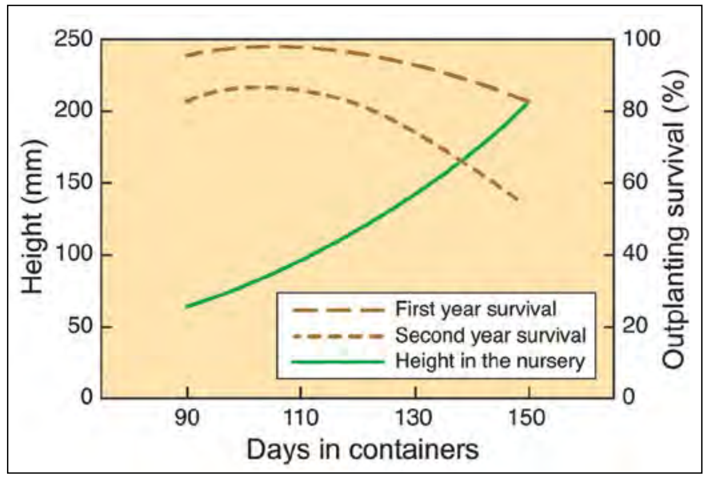


Figure 3. Research done in Sweden with Scots pine shows that survival declined the longer seedlings grew in their containers before outplanting. Adapted from Josefsson (1991) *fide* Rikala (2015).

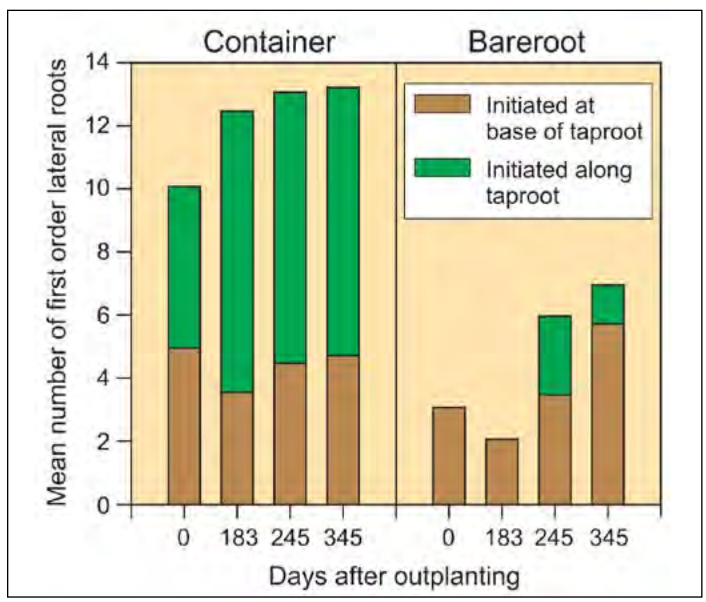


Figure 4. One-year-old northern red oak seedlings grown in containers (Jiffy 5090 Forestry Pellets™; Jiffy Products (N.B.) Ltd., Shippegan, New Brunswick, Canada) had more first order lateral roots originating along, and at the base of, their taproot compared with 2+0 bareroot seedlings at the time of outplanting and 1 year later. Adapted from Wilson et al. (2007).

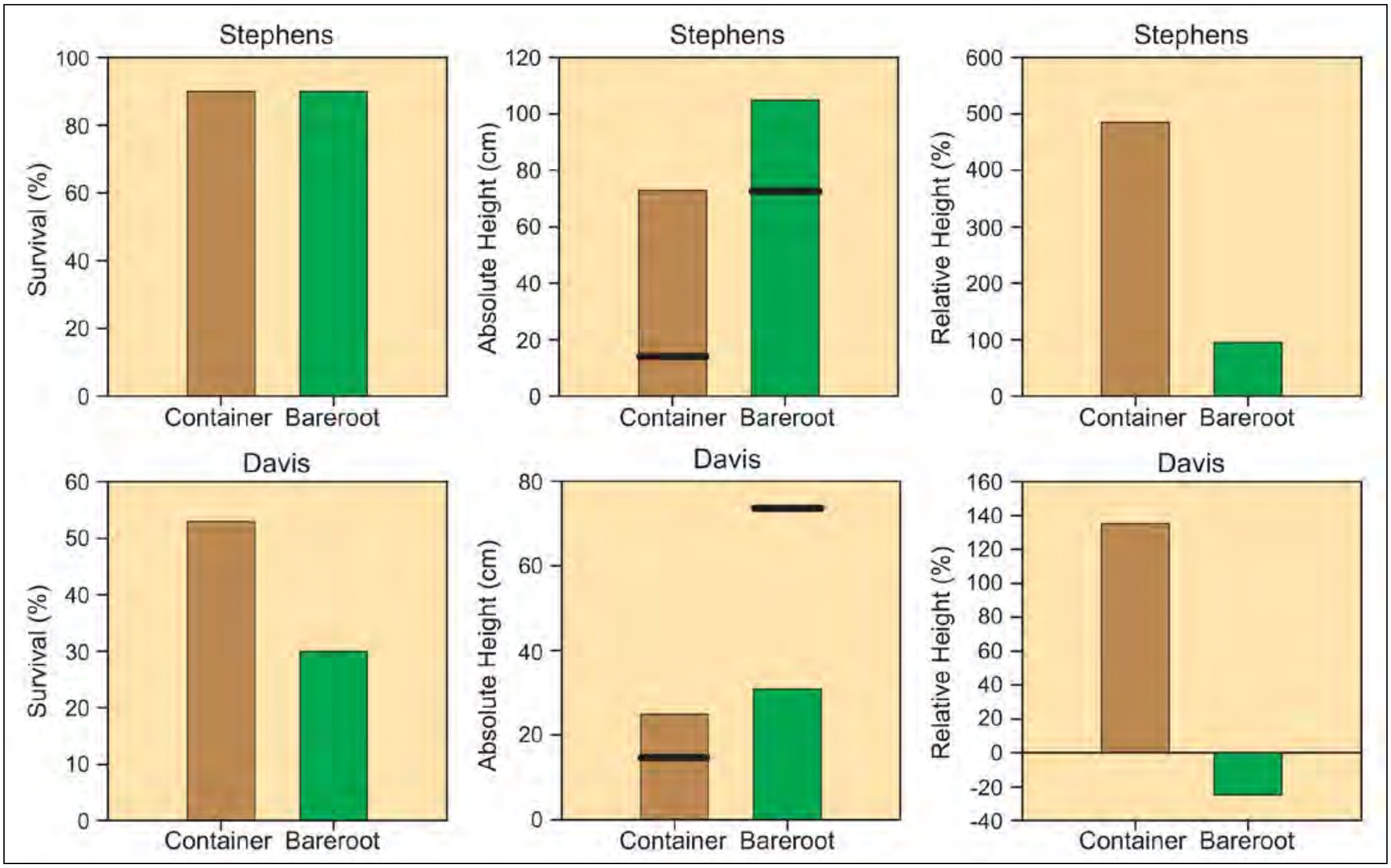


Figure 5. On two upland sites in Indiana (Stephens and Davis), nonbrowsed, 1-year-old container northern red oak (164 m^3 [10 in^3]) had equal or better survival than 1+0 bareroot stock, greater absolute growth (the black horizontal bars indicate height at outplanting), and greater relative growth. (Data courtesy of D.F. Jacobs, from Woolery and Jacobs 2014).

Miniplugs To Improve 1+0s Bed Density and Seedling Quality

In the Western United States, miniplugs developed as a new stock type in the early 1990s continue to be popular for three reasons (Landis 1999, 2007). First, plug+1 seedlings grown entirely in one growing season (6 weeks or so in the greenhouse and the remainder of the growing season in a bareroot bed) can often exceed the quality of traditional 2+0 seedlings. In particular, this stock type develops a very fibrous root system. Second, miniplugs can be transplanted at a more uniform density than can be achieved with machine sowing of seeds (figure 6). Third, nurseries generally do not have to fumigate transplant beds, which, given the increasing costs and restrictions surrounding soil fumigation, adds to the popularity of miniplugs. For seed lots or species with low seed germination or slow growth rates, miniplug transplants may be a way to improve bed density and reduce production time. Although much of the work has been done with conifers, broadleaved trees also thrive as plug+1s; for example, blue oak (*Quercus douglasii* Hook & Arn.) miniplug transplants had similar height and stem diameters compared with 2+0 seedlings, but they had a more fibrous root system (McCreary and Lippitt 1996). The U.S. Department of Agriculture, Forest Service, J. Herbert Stone Nursery (Central Point, OR) is growing some deciduous shrubs as plug+1s (personal observations).

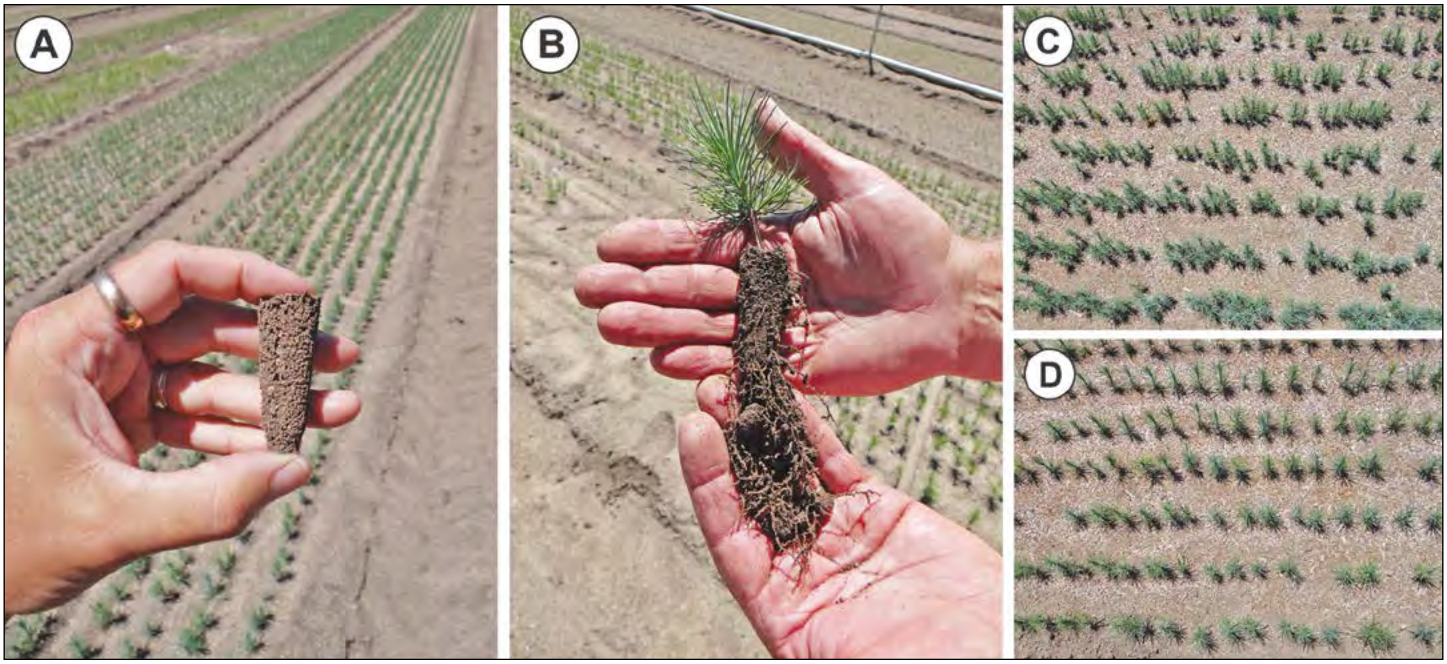


Figure 6. Plug+1 ponderosa pine (*Pinus ponderosa* Lawson & C. Lawson) seedlings growing at the USDA Forest Service, J. Herbert Stone Nursery (Central Point, OR). Production of this stock type begins in early February when stabilized rooting media (QPlug; International Horticulture Technologies, Hollister, CA) (A) is inserted into Hortiblock® 200/19R trays (Beaver Plastics Ltd., Acheson, Alberta, Canada). Plugs are subsequently transplanted into bareroot beds during mid to late April. Rapid growth is evident in the root development after 2 months in the bareroot bed (B). One advantage of transplanting miniplugs is improved bed uniformity; direct sown seeds (C) often have lower bed uniformity than transplants (D). (Photos by R. Kasten Dumroese)

Address correspondence to—

R. Kasten Dumroese, U.S. Department of Agriculture, Forest Service, 1221 South Main Street, Moscow, ID 83843; e-mail: kdumroese@fs.fed.us; phone: 208–883–2324.

Acknowledgments

Trade names are used for the information and convenience of the reader and do not imply endorsement or preferential treatment by the U.S. Department of Agriculture (USDA). This work was supported by the USDA Forest Service, Rocky Mountain Research Station and the National Center for Reforestation, Nurseries, and Genetic Resources.

REFERENCES

Balmer, W.E. 1974. Containerization in the Southeast. In: Tinus, R.W.; Stein, W.I.; Balmer, W.E., eds. Proceedings, North American containerized forest tree seedling symposium. Great Plains Agricultural Council Publication. 68: 38–41.

Barber, J.C. 1982. Reforestation: key to southern forest productivity. In: Guilin, R.W.; Barnett, J.P., eds. Proceedings, southern containerized forest tree seedling conference. Gen. Tech. Rep. SO-37. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station: 3–5.

Barnett, J.P.; Brissette, J.C. 1986. Producing southern pine seedlings in containers. Gen. Tech. Rep. SO-59. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 71 p.

Barnett, J.P.; McGilvray, J.M. 1997. Practical guidelines for producing longleaf pine seedlings in containers. Gen. Tech. Rep. SRS-14. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 28 p.

Dumroese, R.K.; Barnett, J.P. 2004. Container seedling handling and storage in the Southeastern States. In: Riley, L.E.; Dumroese, R.K.; Landis, T.D., tech coords. National proceedings, forest and conservation nursery associations—2003. Proceedings RMRS-P-33. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 22–25.

Dumroese, R.K.; Barnett, J.P.; Jackson, D.P.; Hainds, M.J. 2009. 2008 interim guidelines for growing longleaf pine seedlings in container nurseries. In: Riley, L.E.; Dumroese, R.K., tech coords. National proceedings, forest and conservation nursery associations—2008. Proceedings RMRS-P-58. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 101–107.

Guilin, R.W.; Barnett, J.P., eds. 1982. Proceedings of the southern containerized forest tree seedling conference. Gen. Tech. Rep. SO-37. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 156 p.

Jacobs, D.F.; Salifu, K.F.; Seifert, J.R. 2005. Relative contribution of initial root and shoot morphology in predicting field performance of hardwood seedlings. New Forests. 30: 235–251.

Josefsson, M. 1991. Plantstorlekens betydelse för tallplantornas etablering på biologiskt skilda ståndorter i Norrland—Resultat efter två tillväxtsäsonger i fält av 'Plantstorleksprojektets' Serie C. Sveriges Lantbruksuniversitet, Institutionen för skogsproduktion, Stencil 71. In Swedish.

Landis, T.D. 1999. Miniplug transplants. R6-CP-TP-03-99. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. Forest Nursery Notes. July (1999): 7–8.

Landis, T.D. 2007. Miniplug transplants: producing large plants quickly. R6-CP-TP-01-2007. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. Forest Nursery Notes. Winter (2007): 5–12. http://www.rngr.net/publications/fnn/2007-winter/2007-winter-forest-nursery-notes-1?searchterm=miniplugs. (January 2015).

Landis, T.D. 2010. Managing surplus or holdover nursery stock. Lincoln, NE: U.S. Department of Agriculture, Forest Service, National Agroforestry Center. Forest Nursery Notes. 30(1): 10–12.

Luna, T.; Lindner, D.L.; Dumroese, R.K. 2014. Growing hickories (*Carya* spp.) for roost trees: a method to support conservation of declining bat populations. Native Plants Journal. 15: 66–74.

McCreary, D.; Lippitt, L. 1996. Producing blue oak seedlings: comparing mini-plug transplants to standard bareroot and container stock. In: Landis, T.D.; South, D.B., tech. coords. National proceedings, forest and conservation nursery associations. Gen. Tech. Rep. PNW-GTR-389. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 253–254.

Rikala, R. 2015. Personal communication. Research scientist, retired. Suonenjoki, Finland: Finnish Forest Research Institute.

Salonius, P.; Hallett, R.; Beaton, K.; French, C. 2002. Extended nursery rearing compromises field performance of container-reared conifer seedlings. Info. Rep. M-X-214E. Fredricton, New Brunswick, Canada: Canadian Forest Service, Atlantic Forestry Centre. 21 p.

South, D.B. 2015. A history of container seedling production in the South. Tree Planters' Notes 58(2): 44–55.

South, D.B.; Harris, S.W.; Barnett, J.P.; Hainds, M.J.; Gjerstad, D.H. 2005. Effect of container type and seedling size on survival and early height growth of *Pinus palustris* seedlings in Alabama, U.S.A. Forest Ecology and Management. 204: 385–398.

South, D.B.; Mitchell, R.G. 2006. A root-bound index for evaluating planting stock quality of container-grown pines. Southern African Forestry Journal. 207: 47–54.

Wilson, E.R.; Vitols, K.C.; Park, A. 2007. Root characteristics and growth potential of container and bare-root seedlings of red oak (*Quercus rubra* L.) in Ontario, Canada. New Forests. 34: 163–176.

Woolery, P.O.; Jacobs, D.F. 2014. Planting stock type and seasonality of simulated browsing affect regeneration establishment of *Quercus rubra*. Canadian Journal of Forest Research. 44: 732–739.

Growing in the Cloud: Modern Nursery Data Management Systems

Michael Taylor

Nursery Manager, IFA Nurseries Inc., Canby, OR

Abstract

Today's modern telecommunication and Internet technologies have come a long way to help decrease the amount of paperwork and make information easier to use. Phones are becoming small handheld computers capable of so much more than just a simple phone call. Smart phones have apps for calendar, social media, business functions, and much more. This technology can be used to simplify or improve nursery operations. This article gives an introduction to a few beneficial cloud-based technologies that can make nursery management a little easier, optimize time, provide useful real-time information, and minimize data input and associated errors. This paper was presented at a joint meeting of the Western Forest and Conservation Nursery Association, the Intermountain Container Seedling Growers Association, and the Intertribal Nursery Council (Boise, ID, September 9–11, 2014).

What Is the Cloud and How Can Nurseries Use It?

In the simplest terms, cloud computing means storing and accessing data and programs using the Internet instead of a computer's hard drive. Internet storage eliminates the need to rely on one computer or device. Depending on the cloud service used and how it is configured, information could be available everywhere Internet access is available, and, in some cases, even where Internet access is unavailable. A cloud-based version of most computer-based applications and software can be used on any computer or handheld device. For example, Microsoft® Office is now in the cloud and has the same functionality of Microsoft® Office on any computer or device almost everywhere. One can simply log onto the Web site or open the app on a handheld device and be able to use the programs as needed. The cloud can be used for sales and invoicing, inventory, databases, data storage, e-mail, software, and more. Because many options are available for using technology to improve information flow, it can be difficult to determine which technologies are best suited for a given nursery. Examples of a few cloud-based technologies that can greatly improve nursery functionality and work flow are described in this article.

Syncing Information Across Devices

Several applications make it easy to share data among computers and devices so the most current version of a file is always available to each computer that has access to it. Cloud-based storage options such as Google Drive and Dropbox provide access to files from any device with an Internet connection at a very low cost (table 1). These applications also have options for downloading files for use when not connected to the Internet. By simply downloading the application from its Web site and following the setup instructions, the program will then run in the background and constantly update files as they are changed on any computer or handheld device linked to it. It may seem simple, but these programs are very powerful in their application by allowing access to files, regardless of where one is and what device is in use, and by syncing automatically among computers, phones, and other devices. This system has the added benefit of a real-time backup of all files on a remote, secure server thereby eliminating the need to keep physical data backups. When installing the applications on mobile devices, the files can be physically downloaded to that device, taken into the field for data collection, and then automatically uploaded to all other devices. This ease of access is especially useful for field inventories in locations where Internet connections may not be reliable. Many companies today offer cloud storage, and each program has unique options. Some programs also offer business plans that enable you to control access to specific files and folders.

Table 1. Sample of cloud-based storage options currently available.

Product	Free storage	Price/100 GB/year (2015 U.S. dollars)*	URL
Google Drive	15	23.99	http://www.googledrive.com
Dropbox™	2	11.99	http://www.dropbox.com
Box	5	40.00	http://www.box.com
SugarSync®	5	74.99	http://www.sugarsync.com
MicrosoftOneDrive	7	23.99	http://www.onedrive.com
Apple iCloud	5	23.99	http://www.icloud.com

GB = gigabyte.

*Price is prorated if 100-GB plan is not offered.

Cloud-Based Databases

Most nursery offices have piles of handwritten paperwork with information on seed, sowing dates and locations, culturing, transplanting, packing, shipping, etc., which require someone to manually input that information into a database so it can be used in some manner. These piles of paperwork often get piled according to their importance, and less important paperwork may sit for a very long time before being entered into a computer database. Some paperwork may never get input into a system, because the time required to enter it outweighs the benefit of the information. During busy seasons when other aspects of nursery management require attention, paperwork can go by the wayside. Nurseries can benefit greatly by eliminating paperwork and spending less time entering the information into a mobile device than was previously spent writing it by hand.

Some database programs available today mimic commonly used programs such as Microsoft Excel® or Microsoft Access™, thereby minimizing the transition period and learning curve necessary to use them. With these databases, existing Excel documents can be uploaded to the program's Web site so that important information is available when the new database system is put into operation. When crops are tracked with a unique number or identifier, new information about the crop can be linked to that identifier so existing information does not have to be reentered. This ability to link data is called a relational database and is something to consider when looking at all the databases offered. If linking different tables and information across a database is desired, then a relational database is a must.

After researching a few options, we chose TrackVia (http://www.trackvia.com, Denver, CO) for use at IFA Nurseries (which grew out of the old Industrial Forestry Association) in Canby, OR. TrackVia is an online database that offers a mobile interface and full access on both desktop and mobile devices. It is described as a "do-it-yourself workflow software platform for business users." The following sections describe a few nursery operations in which this technology has been applied at IFA Nurseries to assist with information collection and data flow.

Cultural Practices

Nursery cultural practices are anything done to the crop during its growth cycle. Culturing includes fertilizer and chemical applications, pest management, root pruning, quality testing, etc. Using cloud-based databases has been a huge help in information flow and recordkeeping and has significantly improved our overall efficiency.

We have one master table with a list of every chemical we use, along with rates, U.S. Environmental Protection Agency numbers, reentry intervals, necessary personal protective equipment, chemical classes, etc. (figure 1). As we walk through the crop to determine pest management needs, we can simply add a new chemical application (or cultural practice) to the task list and let our operators know a new chemical application or culturing practice has been posted (figure 2). The tasks are ordered by importance and the operators simply access the database on their mobile device and select each task to get all the information they need to properly apply the chemical or cultural treatment (figure 3). After the application is complete, the operators input when and where they applied

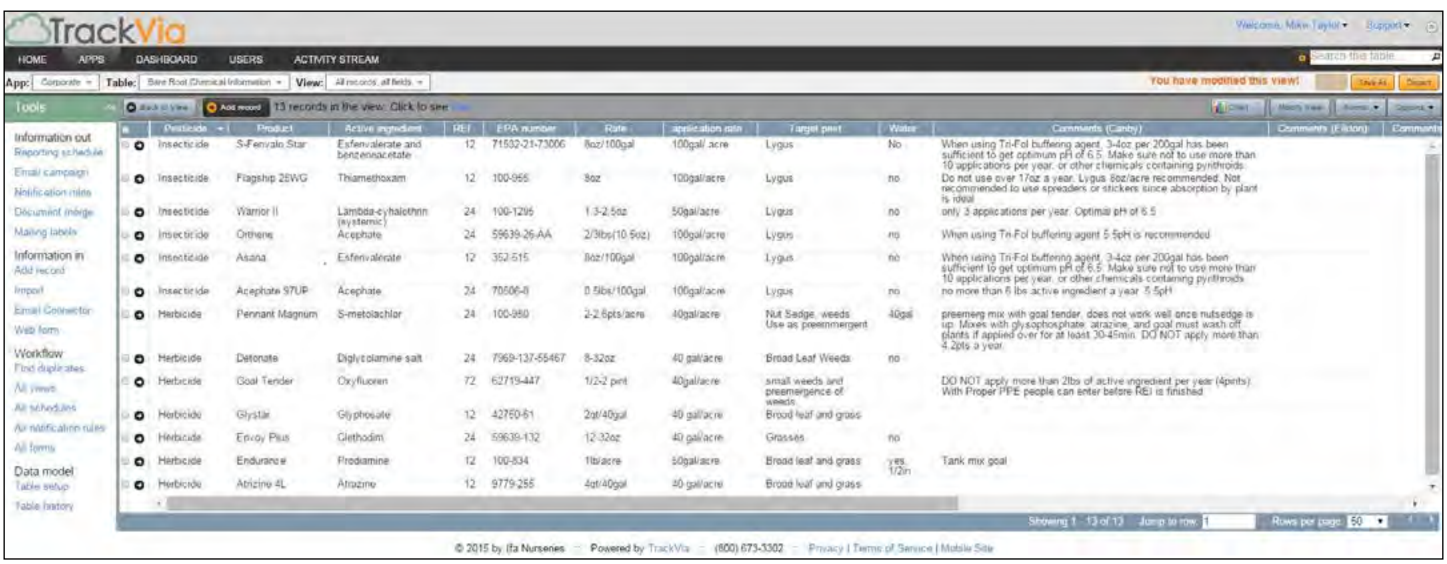
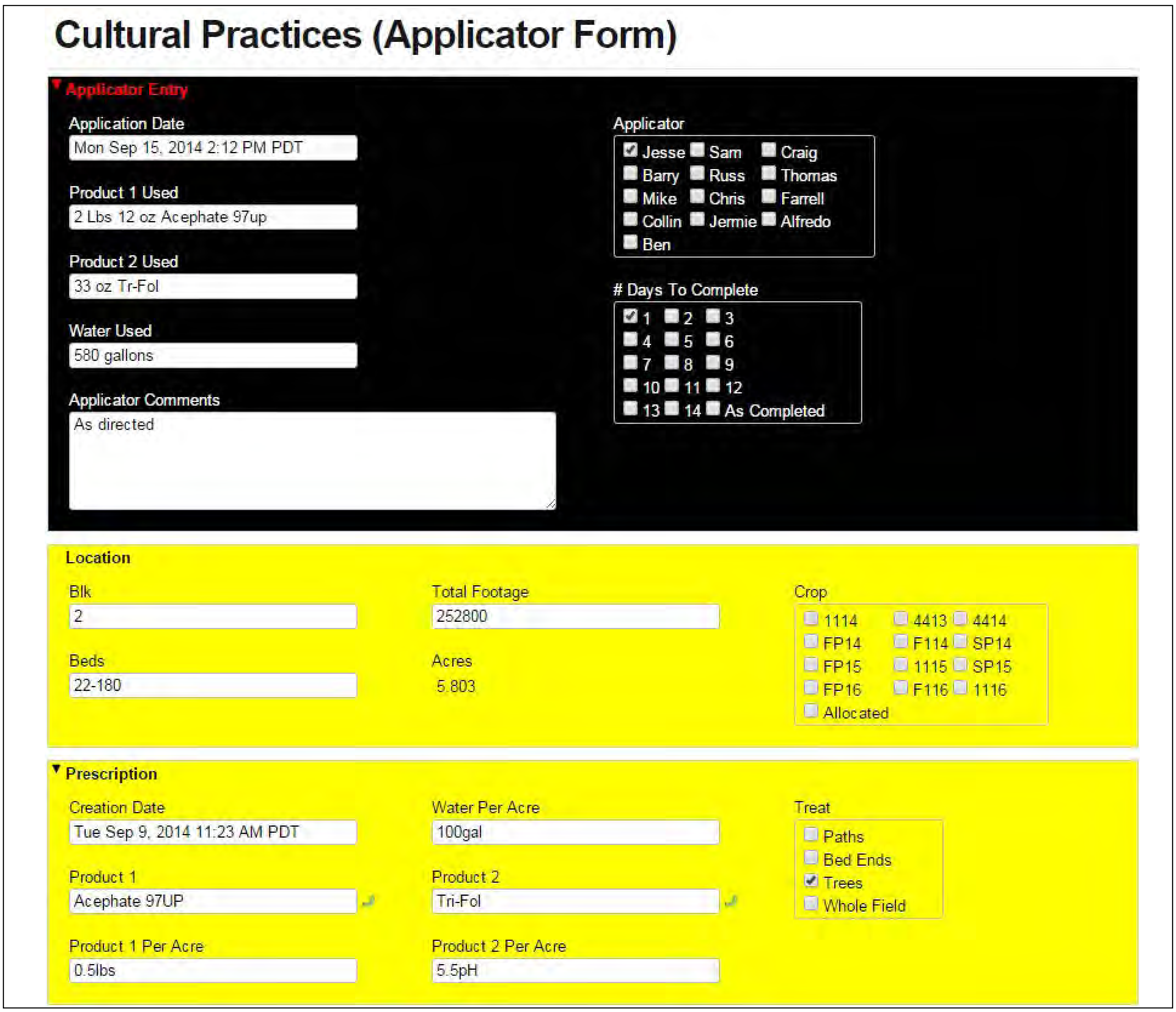


Figure 1. A cloud-based, detailed chemical information table is used to give specific information about nursery chemicals, such as rates, proper usage, target pest(s), and U.S. Environmental Protection Agency numbers.

Figure 2. An equipment operator looking up fertilizer recommendations on his mobile device to see product and rate information and application location. (Photo by Mike Taylor, 2015)

the treatment(s) and the amount of any chemicals they used. This system has enabled us to efficiently keep track of our chemical usage and have a running list of everything we have applied or have done to a given crop at the click of a button. Now, when we are out in the field with customers and they ask what has been done to their crop, we can immediately access a list of dates and activities for their crop on a mobile device. Also, when it is time to order more chemicals or fertilizers, the database provides an inventory of exactly how much chemical has been used in the past, thereby enabling us to accurately estimate future needs.


Cultural Practices (Applicator Form)

Applicator Entry

Application Date: Mon Sep 15, 2014 2:12 PM PDT

Product 1 Used: 2 Lbs 12 oz Acephate 97up

Product 2 Used: 33 oz Tr-Fol

Water Used: 580 gallons

Applicator Comments: As directed

Applicator: Jesse (checked), Sam, Craig, Barry, Russ, Thomas, Mike, Chris, Farrell, Collin, Jermie, Alfredo, Ben

Days To Complete: 1 (checked), 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, As Completed

Location

Blk: 2

Beds: 22-180

Total Footage: 252800

Acres: 5.803

Crop: 1114, 4413, 4414, FP14, F114, SP14, FP15, 1115, SP15, FP16, F116, 1116, Allocated

Prescription

Creation Date: Tue Sep 9, 2014 11:23 AM PDT

Product 1: Acephate 97UP

Product 1 Per Acre: 0.5lbs

Water Per Acre: 100gal

Product 2: Tri-Fol

Product 2 Per Acre: 5.5pH

Treat: Paths, Bed Ends, Trees (checked), Whole Field

Figure 3. A sample cloud-based cultural practices form that applicators at IFA Nurseries use when applying chemicals.

Lifting and Packing

Another area of our operation in which using TrackVia has increased efficiency and decreased paperwork is lifting and packing operations. Lifting and packing season is the busiest season we have, because all the stock will be lifted and shipped or stored during a few short months. It is also the season when the ability to stay abreast of paperwork is at its worst. In the past, we would print a list of beds or crops we wanted to lift that day and hand it to our lifting operator. The operator would then fill out the information such as the number of workers, start times, stop times, beds, etc. At the end of the day, the operator would give the paperwork to someone in the office who would then enter it into a computer-based Microsoft Excel® or Microsoft Access™ database. Since introducing TrackVia, the operators have been carrying mobile tablets on which they can access real-time information about each nursery bed and the lifting schedule priorities. As the operators complete the work, they enter the date and time, comments, number of lifters, and other details. The database then automatically calculates the labor production as the operator enters the information. This system also enables the manager to easily change the scheduling priorities based on conditions or needs; these changes show up immediately in the operators' tablets.

Another useful piece of information we are tracking in the cloud is cull data. In the past, all cull data was input on the back of the packing forms and never input into any database because the volume of information was too much and we rarely used the information. Now, as the packing line leaders do their quality checks in the packing shed, they enter the lot number and its corresponding cull data. The cull data is displayed graphically in real time as the information is being collected. This feature has provided a unique retrospective examination of our crop types to gauge the quality of each so we can improve in subsequent seasons.

Shipping and receiving information has also been very useful to keep in TrackVia. It enables us to link current pack production and volume to a specific customer. After the information is linked, we can bring up a specific customer's name and see every lot that the customer has in the cooler or freezer and lots that have not yet been lifted. This approach enables us to readily see the total lots packed and shipped and to determine the balance remaining for each customer.

By tracking all this information in the cloud, we have a powerful database for real-time tracking of crop information, as well as for following the progression of seedling lots over multiple years. In addition to recording data, we can add "dashboards" within the program to build graphs to summarize information across tables. These graphs update as we input information. For each season, we create graphs for transplant production, packing production, sowing, etc., to gauge efficiency. With all the information in one place, we are able to keep track of daily production and the production among crews.

Cloud-Based Control Systems

Irrigation scheduling at our greenhouse is a full-time job. In the past, irrigators had to do a lot of walking through the crop and then walking back to a computer to schedule the irrigation. Now, irrigators have a tablet or smartphone that can turn on and set irrigation schedules as they walk around the greenhouse (figure 4). In addition, we are able to control irrigation applications using a cloud-based system. Opensprinkler (Rayshobby Shop, Amherst, MA, at http://www.rayshobby.net) is a Wi-Fi based irrigation controller that uses an app on a mobile device or Web site to set irrigation schedules and run programs (figure 5). It enables anyone with Wi-Fi or Internet access to instantly turn sprinklers on and off. The program includes the ability to input restrictions to prevent turning on more irrigation lines than the pump can support. Irrigation zones can be prioritized and put into a queue; the system will turn on the next irrigation zone when the current zone finishes. It has been a very valuable time saver and solved a lot of logistical and timing issues. The system is easy to set up and very inexpensive compared with a computer-based system and integrates easily with handheld devices and computers.

Figure 4. Scheduling irrigation inside one of the greenhouses using a mobile device. (Photo by Mike Taylor, 2015)

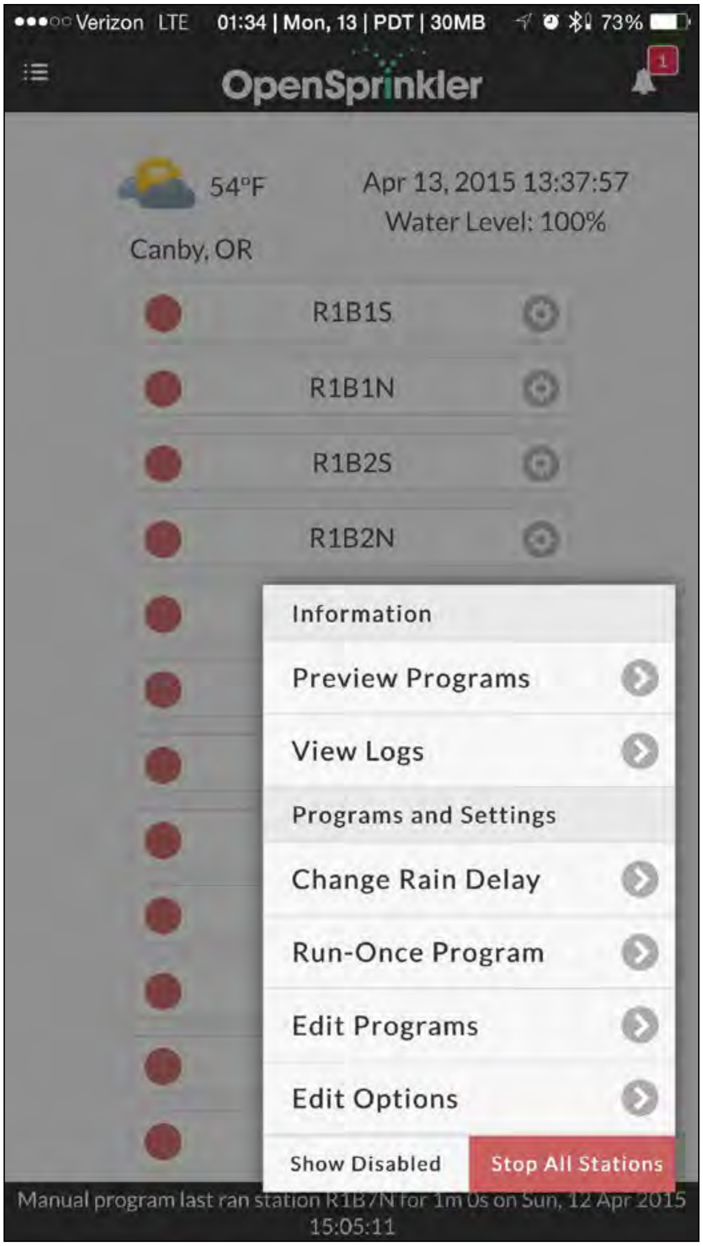


Figure 5. Open Sprinkler is a cloud-based system for controlling irrigation. This screenshot shows basic irrigation scheduling options in the system's mobile app.

Considerations for Selecting a Cloud-Based Database

It is important to consider a few things before starting to use a cloud-based system. First, not everything is most efficient when directly input into the cloud. As mentioned previously, we download our inventory files to our tablets for input during the day and then upload them back to the cloud at the end of the day. Cellular and Wi-Fi connections, however, are not always the best choice when constantly updating a file in the field. Even though we have great mobile service in our fields, it does not always have a good connection to the site and data can be lost if we are not careful. This system can also be a big drain on phone batteries using a cellular connection, but using a physical file on a tablet does not use nearly as much. Second, it may not be desirable to directly enter everything into the database. For instance, we decided to have pack volume and production entered into the database directly by the line leaders in the packing shed, but we chose to enter actual volume packed later, after we double check the numbers. An accurate pack volume is worth the extra data entry compared with troubleshooting errors at a later time. Third, and last, it will take time to develop cloud-based applications to be useful and efficient for a given operation. We started out in the summer by adding cultural practices, and then before every season, we added more functionality and made adjustments as we went along. Upon initial use, the system may not be exactly as desired, but with trial and error and input from others who use it, it will become more efficient and easier to use over time.

Address correspondence to—

Michael Taylor, Nursery Manager, IFA Nurseries Inc., 1887 N. Holly Street, Canby, OR 97013; e-mail: mtaylor@ifanurseries.com; phone: 503–805–1222.

Recent Technology and Development at the Forest Service Nurseries

Ed Messerlie and Gary Kees

Program Leader, Technology and Development Program, U.S. Department of Agriculture (USDA), Forest Service, Missoula, MT; Project Leader, Technology and Development Program, USDA Forest Service, Missoula, MT

Abstract

The U.S. Department of Agriculture (USDA), Forest Service, Technology and Development (T&D) program works on a variety of projects for the reforestation, nurseries, and genetics programs. During the past few years, the T&D program has developed a tree planter pulled by a utility terrain vehicle and a seed dryer designed to dry small quantities of seed. Midmount tractors were evaluated to compare their cost and usefulness with rear- and front-mount tractors. After building a steam room for one of the USDA Forest Service nurseries, T&D developed design guidelines that could be applied to build steam rooms from new or existing facilities. Finally, the T&D program has been helping the USDA Forest Service nurseries update their data management systems. This paper was presented at a joint meeting of the Northeast Forest and Conservation Nursery Association and Southern Forest Nursery Association (Williamsburg, VA, July 21–24, 2014) and a joint meeting of the Western Forest and Conservation Nursery Association, the Intermountain Container Seedling Growers Association, and the Intertribal Nursery Council (Boise, ID, September 9–11, 2014).

Introduction

The U.S. Department of Agriculture (USDA), Forest Service, Technology and Development (T&D) program began in the 1940s to develop wildland firefighting equipment. Two facilities developed the equipment in Missoula, MT, and San Dimas, CA. Over time, the USDA Forest Service added other program areas, such as engineering, range management, recreation, forest management, reforestation, nurseries, genetics, and many more. Today, the T&D program manages specifications, develops equipment and training, and evaluates tools for many program areas internal and external to the USDA Forest Service. This article covers some recent projects completed by the Reforestation, Nurseries, and Genetics Resources T&D program.

Mid-Mount Tractor Evaluation

The purpose of the mid-mount tractor evaluation project was to purchase and evaluate two new mid-mount tractors to determine their cost effectiveness and usefulness compared with front-mount and rear-mount tractors. T&D purchased the Italian-made Mazzotti Multi 600 Tool Carrier 4x4 mid-mount tractor (Mazzotti Company, Ravenna, Italy) (figure 1). The Mazzotti has four-wheel drive and a 60 horsepower Perkins diesel engine. Wheel width adjusts from 59 to 82 in (150 to 210 cm). The span between the front wheels and the rear of the machine can be adjusted by 29 in (74 cm) to accommodate various sizes of implements.

Figure 1. Mazzotti mid-mount tractor cultivating a red oak seedling bed. (Photo by Christy Makuck, USDA Forest Service, 2012)

T&D also purchased the Saukville High Boy mid-mount tractor (this tractor is no longer manufactured or available) (figure 2), which resembles a slightly larger Model G implement carrier tractor (Allis-Chalmers Manufacturing Company, Milwaukee, WI); the Model G was an iconic piece of machinery at bare-root nurseries nationwide. The Saukville High Boy has 27 in (67 cm) of clearance. At the time of purchase, the manufacturer had just begun building units after purchasing the rights to the design. The company has since sold its equipment line, and the Saukville is no longer in production.

Specifications for each tractor are shown in table 1.

Figure 2. Saukville mid-mount tractor with cultivator. (Photo by Gary Kees, 2010)

The main advantage of a mid-mount tractor compared with front-mount and rear-mount tractors is the increased visibility of the implement and seedling row. This visibility provides the operator greater control and allows for single-person operation of mechanical in-row practices (e.g., weeding and vertical root pruning). The mid-mount option also enables the operator to perform an additional practice, such as fertilizing, by attaching a fertilizer implement behind the tractor.

Because of its smaller size, the Saukville tractor is more maneuverable than the Mazzotti tractor. The Saukville's rear, three-point lift arms were loosely constructed making it difficult to cultivate close to the row crop (both the front and rear are poorly designed). Because of the light weight of the front end, the nursery added additional forward weight on the Saukville to keep the front end from wandering.

The large, heavy size and high cost of the Mazzotti are big detractors. This tractor works well, but it is not as nimble and quick as the Saukville. In addition, the Mazzotti tractor's height makes it difficult to see smaller plants when performing treatments.

Knife Cultivator

The T&D program built a new knife cultivator from old technology (figure 3) to address the need for cultivating around small forbs and grass seedlings without disrupting the soil. A lightweight knife blade, designed similar to the old push cultivator used in a small garden plot, was attached to a cultivator bar mounted under a tractor. The knives are very thin and sharp. The cultivator is designed to cut weeds without disturbing the soil. This process limits the risk of tearing out big clods along with the native plants. The T&D knife cultivator has a set of gauge wheels and the tool standards are spring loaded to protect the knife if they hit rocks. The knife cultivator worked very well unless the weeds became larger than approximately 6 in (15 cm) tall. Taller, wet weeds tended to plug up in the knife blade supports. In addition, very hard ground wore the knives quickly. In soft and loamy ground, such as at the USDA Forest Service Bessey Nursery (Halsey, NE), the weeds would not cut, and they collected on the knife blades.

T&D tested a similarly designed cultivator, commercially available from Buckeye Tractor Co (Columbus Grove, OH). The Buckeye Tractor cultivator proved to function as well as the T&D cultivator. Both knife cultivators are designed so that the spacing among knives can be adjusted as needed.

Table 1. Specifications for the two mid-mount tractors evaluated by MTDC.

Specifications	Saukville High Boy	Mazzotti Multi 600 Tool Carrier 4x4
Hitch	Three-point category one, middle and rear, rear drawbar	Three-point category two, middle (2,200 lb [4,840 kg] lift) and rear (3,300 lb [7,260 kg] lift), rear drawbar
Engine	37 hp Cummins diesel	60 hp Perkins diesel, four cylinder
Transmission/drive	Variable speed hydrostatic Sauer-Danfoss transaxle with hi-low range, two-wheel drive	Two variable speed ranges, four-wheel hydraulic
PTO	Mid-mounted hydraulic, 540 rpm	Mid-mounted hydraulic, 540 rpm
Brakes	Rear separate discs	Four-wheel hydraulic
Tires	Front: 5.00 -12; rear: 8.30 -24	Front: 7.5 R18; rear: 9.5 R32
Wheel width adjustment	Front: 56 to 72 in (142 to 183 cm); rear: 48 to 68 in (122 to 173 cm)	Front and rear: 59 to 82 in (150 to 210 cm)
Wheelbase length	Variable 105 in (267 cm); overall variable 161 in (409 cm)	Variable 101 to 130 in (256 to 330 cm); overall variable 153 to 182 in (389 to 462 cm)
Weight	3,500 lb (7,700 kg)	5,290 lb (11,638 kg)
Fuel capacity	12 gal (45.4 L)	12.5 gal (47 L)
MTDC purchase price in 2013	$24,490	$85,000
Contact information	No longer being commercially manufactured	Bartschi-Fobro, Inc., Grand Haven, MI

hp = horsepower. MTDC = Missoula Technology and Development Center. PTO = power take off. rpm = revolutions per minute.

Figure 3. Technology and Development program knife cultivator mounted on the Mazzotti mid-mount tractor. (Photo by Gary Kees, 2012)

Small Lot Seed Dryer

The small lot seed dryer (figure 4) was built at the request of the USDA Forest Service Lucky Peak Nursery (Boise, ID) based on an idea demonstrated by Bob Karrfalt at the USDA Forest Service, National Seed Laboratory (Dry Branch, GA). Karrfalt presented his idea at the annual Western Forest and Conservation Nursery Association meeting in Bend, OR, in 2012 and later published his design (Karrfalt 2014). The T&D program took Karrfalt's idea and created a slightly more robust unit using seed trays that the Lucky Peak Nursery was already using. The T&D-developed dryer has a base with a fan and heating element. A plenum sits on top of the base and houses five seed trays (17 by 17 by 2.25 in [43 by 43 by 5.70 cm]). Air is blown up through the plenum and across the trays, exiting in the front. The user can control both fan speed and temperature. The unit is designed to provide airflow ranging from 5.6 to 37.0 cfm (9.5 to 62.9 m^3/hr) at 100.0 °F (37.8 °C). The plenum is designed to ensure the same airflow across all five trays.

Figure 4. Small lot seed dryer developed by the Technology and Development program. (Photo by Gary Kees, 2014)

UTV-Pulled Tree Planter

Lucky Peak Nursery submitted a proposal to the T&D program to locate or develop a mechanical tree planter that could be towed by an all-terrain vehicle (ATV). It is much easier to train personnel to operate an ATV or utility terrain vehicle (UTV) than a tractor. This type of planter would also be able to plant seedlings in wetlands and areas not accessible with a tractor. The planter had to be capable of planting 2-year-old tree stock. It had to be maneuverable and the coulter blade and planting shoe had to be capable of being lifted out of the ground for turning. It was desirable to have both the ATV and planter fit on a small trailer or in the back of a pickup truck.

A wagon-like cart was designed to carry the planter and its operator (figure 5). The coulter blade and shoe were designed with a parallel link that keeps the planting shoe level at all depths. This design allows the operator and packing wheels to stay on the ground; only the coulter and trencher are raised when making corners. The design includes a 12-volt, electrically activated hydraulic pump and cylinder for raising the

Figure 5. The utility terrain vehicle (UTV) tree planter for planting seedlings at the Lucky Peak Nursery. (Photo by Clark Fleege, USDA Forest Service, 2014)

coulter blade and planting shoe. The seats, packing wheels, and plant boxes are made by the Holland Transplanter Company (Holland, MI).

Initial testing of the tree planter proved that an ATV would not be able to pull the planter so the project focus was changed to develop a UTV-pulled mechanical tree seedling planter. A diesel John Deere Gator UTV was used for this project (Deere & Company, Moline, IL). The power and weight of the Gator is marginally adequate. The biggest issue is maintaining traction in difficult soil conditions. Initial tests were conducted at the Lucky Peak Nursery in the summer when the ground was hard. At times, lowering the coulter and shoe lifted the transplanter wheels off the ground. In softer soil, however, the shoe developed an adequate slot and was able to plant some stock that Lucky Peak had available.

It is expected that pulling the UTV tree planter in softer soil conditions during typical spring planting conditions should work. While the UTV tree planter can be towed in the field at lower speeds, it is not designed to be towed at highway speeds. The UTV tree planter fits in the back of a pickup truck or small trailer but not with the UTV. The UTV planter can easily be towed by a pickup truck or jeep. A complete set of drawings for the UTV-pulled mechanical tree planter is available from T&D (drawing MTDC-1104).

Steam Room Design Guidelines

The USDA Forest Service Toumey Nursery (Watersmeet, MI) and the USDA Forest Service Bessey Nursery asked T&D to develop "Steam Room Design Guidelines" for construction of steam rooms at their facilities. In 2004, the T&D program developed a steam room (figure 6) to sterilize large lots of polystyrene seedling blocks for the Lucky Peak Nursery by converting a walkin cooler using a steam boiler and some piping (Trent et al. 2005). The steam room greatly decreases the labor and time required to sterilize seedling blocks. Rather than specifying a one-off design, the T&D program developed design guidelines to enable nursery managers to specify requirements for the steam boiler. The guidelines direct the nursery manager through a series of questions and recommendations to collect data required for a boiler company to properly size the boiler. A properly sized boiler is capable of heating the room to 160 °F (71 °C) within an acceptable amount of time. The Lucky Peak Nursery starts its boiler at around 6:30 a.m. At approximately 5:00 p.m., the room reaches 160 °F (71 °C) and they shut the boiler off. The steam room doors remain closed overnight and are opened in the morning.

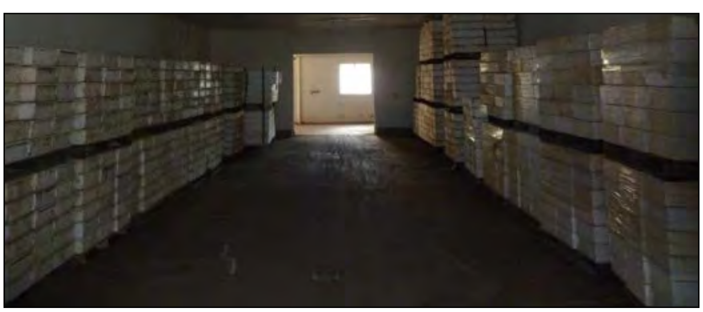


Figure 6. Interior of the Lucky Peak Nursery steam room. (Photo by Clark Fleege, USDA Forest Service, 2013)

Nursery Management Information System

The Nursery Management Information System (NMIS) is a database system that the USDA Forest Service nurseries use to track inventories (seed and seedlings), process sowing requests, and prepare billing statements. Two systems are currently in use: an Access database and an Oracle database. Each database has different functionality. The T&D program is working with the nurseries to combine the two databases and improve the system. We are investigating hosting and maintenance solutions to ensure future viability of the databases.

Conclusion

The T&D program receives project ideas from people all over the country. Anyone interested in submitting an idea can contact the T&D program at 909–599–1267 or 406–329–3900. Additional information about the projects described in this article and other projects completed by the T&D program are available on our Web site: http://www.fs.fed.us/t-d/.

Address correspondence to—

Ed Messerlie, Program Leader, Technology and Development Program, U.S. Department of Agriculture, Forest Service, 444 E. Bonita Avenue, San Dimas, CA 91773; e-mail: emesserlie@fs.fed.us.

REFERENCES

Karrfalt, R.P. 2014. Assembling seed moisture testers, seed dryers, and cone dryers from repurposed components. Tree Planters' Notes. 57(2): 11–17.

Trent, A.; James, R.; Fleege, C.; Hileman, G. 2005. Using a steam-room to sterilize pallets of styrofoam seedling container blocks. Tech. Rep. 0524–2808–MTDC. Missoula, MT: U.S. Department of Agriculture, Forest Service, Missoula Technology and Development Center. 10 p.

Using Plant Growth Regulators on Red Alder and Douglas-Fir Plugs

Nabil Khadduri

Nursery Scientist, Webster Forest Nursery, Washington Department of Natural Resources, Olympia, WA

Abstract

Treatments of 50 ppm, 50 ppm (two applications), 100 ppm, and 200 ppm and also 5 and 10 ppm drench applications of the plant growth regulator (PGR) Bonzi® (paclobutrazol) significantly reduced height growth while maintaining stem diameter growth in red alder (*Alnus rubra* Bong.) container seedlings, resulting in a sturdy, compact seedling at transplant. Although the use of PGR facilitated the midseason transplanting process, end-of-season height, stem diameter, and packout totals of field-transplanted seedlings were not significantly different than the control group. In a second trial, Bonzi and Sumagic® (uniconazole-P) PGRs were applied to coastal Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) container seedlings to help stimulate shutdown. Treatments of 10, 20, and 40 ppm Sumagic® significantly reduced height growth compared with control seedlings, but stem diameter growth was significantly reduced as well. Bonzi® treatments of 50, 100, and 200 ppm did not significantly reduce height growth, while stem diameter growth was slightly lower than controls. Only the 10 ppm Sumagic® treatment produced sturdier (lower height-to-stem diameter ratio) seedlings compared with control seedlings. Used in conjunction with other cultural techniques, PGRs may offer the grower another tool to manipulate seedling growth. At this time, PGRs show more promise in red alder than Douglas-fir seedling production. This paper was presented at a joint meeting of the Western Forest and Conservation Nursery Association, the Intermountain Container Seedling Growers Association, and the Intertribal Nursery Council (Boise, ID, September 9–11, 2014).

Introduction

Both red alder (*Alnus rubra* Bong.) and coastal Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) are known for their rapid, at times excessive, vegetative growth in nursery culture. While a grower must push the production cycle to achieve final root and stem morphology specifications in one season, plant growth regulators (PGRs) might help moderate rapid height growth in the goal of producing a balanced seedling.

The bulk of PGR research on Pacific Northwest reforestation species was done in the late 1980s and early 1990s following the release of paclobutrazol (Bonzi®, Syngenta, Wilmington, DE). Wheeler (1987) found no effect of paclobutrazol on 4- to 5-year-old Douglas-fir seed orchard trees, but did note height reduction when applied to 6-week-old seedlings. van den Driessche (1988) found that, in sand culture, paclobutrazol reduced height and shoot:root ratios of Douglas-fir seedlings. Rietveld (1988) used Bonzi® over pine (*Pinus* spp.) in a bare-root nursery to successfully achieve height control. He noted the disadvantage of using a PGR, however, because of the residual nature of the chemical in the soil for up to 2 years. In a three-nursery study, Smith et al. (1994) found that sturdiness quotients (height to stem diameter ratios) of western larch (*Larix occidentalis* Nutt.), white spruce (*Picea canadensis* (Mill.) Britton, Sterns & Poggenb.), and lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.) were all improved with Bonzi® applications, without negative effects on root growth.

Despite these promising early results, little research exists on paclobutrazol or any other PGR applied to reforestation species in the past 20 years. Two possible explanations are the early experiences of some growers when applying excessively high rates of PGR that resulted in stunting of seedlings for multiple seasons. Also, patents for chemicals such as paclobutrazol have since expired. While paclobutrazol and other PGRs are still considered expensive, several companies now make these products and the price has dropped. For example, paclobutrazol is now sold as Paczol® (OHP, Inc., Mainland, PA), Downsize® (Greenleaf Chemical, Henderson, NV), and Piccolo® (Fine Americas, Walnut Creek, CA), in addition to Bonzi®.

Duck et al. (2004) investigated foliar application of commonly used PGRs to several conifer species for tabletop Christmas tree production. They found that uniconazole (Sumagic®, Sumitomo Chemical, New York, NY; also sold as Concise®, Fine Americas) was most effective in controlling height growth across a range of *Pinaceae* and *Cupressaceae* species. Like paclobutrazol, uniconazole is a triazole (PGR Mode of Action 1), but is not labeled for chemigation or outdoor nursery use. Uniconazole-P is considered the most potent PGR available (Runkle 2013) (figure 1).

The active ingredient of most PGRs can be absorbed through stems and roots. Spray-to-wet applications, in which an

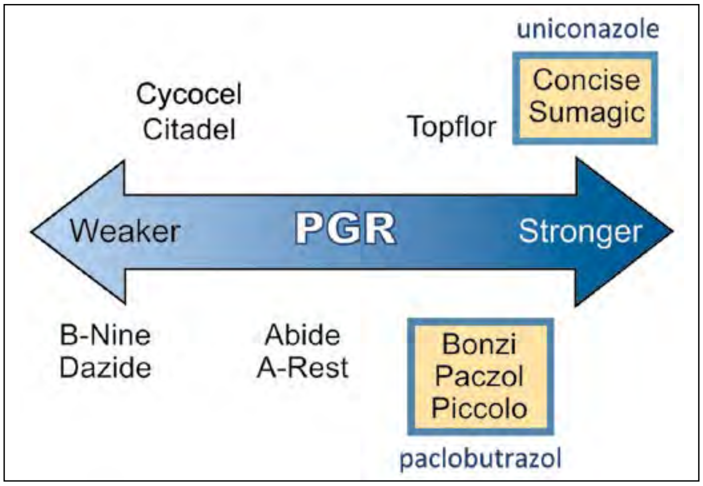


Figure 1. Relative strengths of commonly used plant growth regulators (PGRs). Adapted from Runkle (2013).

appropriate volume of solution is applied to the point of first runoff from foliage, focus on stem uptake, whereas drench applications are primarily taken up through roots. After the chemical is in the plant, it is transported through the xylem tissue and inhibits gibberellin synthesis. The most noticeable effect is the development of shorter stem internodes (with accompanying height reduction) due to smaller, more compact cell development. Other changes, such as in poinsettia production, may include thicker stems, increased rooting, darker green leaves (due to increased chlorophyll production), and improved water use efficiency (Lattimer and Whipker 2012).

It is important to apply PGRs in conjunction with sound cultural practices. "Wet" growers will find less use for PGRs, because keeping seedlings constantly wet may override or dilute PGR effects. In general, higher rates of PGRs are needed for crops grown in warm climates, high light intensity, wet growing medium, high fertilization, tight plant spacing, and with vigorous species. Conversely, lower rates of PGRs can be used in cooler, lower light, drier, lower fertility, wider plant spacing, and with less vigorous species. Note that PGRs can be tied up by bark media mixes and will require higher rates in this situation or may not be effective at all (Currey and Lopez 2010). Accurate application is also vital. Along with product concentration, the volume of application will determine the longevity of the product in the plant. Foliar sprays tend to have the shortest effect, dips have a moderate-lasting effect, and substrate drenches have the longest effect (Runkle 2013).

The objective of this study was to test (1) the effects of paclobutrazol (Bonzi®) on red alder and (2) to compare uniconazole (Sumagic®) with Bonzi® on Douglas-fir. Knowing that conifers are less affected by PGRs than hardwoods and herbaceous perennials, we chose to include Sumagic® in the Douglas-fir trial (trial 2) for its high activity.

Materials and Methods

Trial 1: Bonzi® Applications on Red Alder Small Plugs for Transplant

At the Department of Natural Resources, L.T. Mike Webster Nursery (Olympia, WA), we grow red alder seedlings as a plug+1/2. This stocktype consists of roughly 3 months grown as a container seedling (plug) followed by 5 or so months in a bareroot field. The challenge for a greenhouse grower is to achieve good root fill in the plug cavity without excessive height at the end of the plug stage. These targets can be achieved in part with moisture and nutrient management, but red alder has a notoriously sensitive plant wilting point and does not always react well to reduced irrigation. A tall, skinny plug seedling can be hard to transplant to the bareroot field, because it may get caught in the wheels of a mechanical transplanter or fail to stand up well after transplanting. Hot weather in the first couple of weeks following transplanting can damage the greenhouse-grown leaves and plants may decline before adequate soil-root contact has been established. The goal of this trial was to achieve a more compact seedling able to withstand the rigors of transplanting.

Red alder seed was sown in late February 2014 in 2 in^3 (40 ml) 240-cell Styroblock™ Containers (Beaver Plastics, Acheson, Alberta, Canada) in an 80:20 peat:perlite medium. Four seed lots, representing the four lowland red alder seed zones of western Washington, were included in the trial in a randomized complete block design (blocked by seed lot).

We applied a range of Bonzi® treatments in our greenhouse facility (table 1). Capsil® (Aquatrols, Paulsboro, NJ), a nonionic adjuvant, was added to lower treatment rates and to determine if it would enhance treatment effects. Treatments were applied with a backpack sprayer April 17, 2014, 7 to 8 weeks after sowing. Whole Styroblocks™ (240 seedlings) were treated within each seed lot (block), randomly assigned a location in the greenhouse, and grown under operational growing conditions. Spray treatments wetted the foliage just to the point of runoff. Drench treatment volumes of approximately 1.5 fl oz (44.0 ml) solution per cell were applied to achieve roughly 10 percent leaching from application.

Seedling heights were measured every 2 weeks following transplant through the end of the growing season in early November. Stem diameters were measured 6 weeks after treatment (upon lifting from containers and transplanting to the bareroot field) and at the end of the growing season. ANOVA analyses were conducted using the R statistical

Table 1. PGR treatments applied to red alder container seedlings.

Treatment	Rate (ppm)	Application method	Number of applications	Adjuvant
Control	NA	NA	NA	NA
Bonzi®	50	Spray	One	None
Bonzi®	50	Spray	One	Capsil*
Bonzi®	50	Spray	Two, 17 days apart	None
Bonzi®	100	Spray	One	None
Bonzi®	100	Spray	One	Capsil*
Bonzi®	200	Spray	One	None
Bonzi®	5	Drench	One	None
Bonzi®	10	Drench	One	None

NA = not applicable. PGR = plant growth regulator.

*Applied at a rate of 0.10 oz/gal (0.75 g/L).

package (R Core Team 2013). Treatment means were subjected to Tukey's HSD test and considered significantly different at the $p < 0.05$ level.

Trial 2: Bonzi® and Sumagic® Applications on Large Douglas-Fir Plugs for Outplant

Perhaps the main challenge a grower faces in culturing large, coastal Douglas-fir plugs is effectively shutting down shoot growth in late summer. Timely shutdown results in improved shoot:root and sturdiness quotient, while timely budset correlates with earlier development of cold hardiness. The goal of this trial was to evaluate the efficacy of the PGRs Bonzi® and the more active Sumagic® in limiting late-season Douglas-fir top-growth.

Douglas-fir seed was sown in mid-February 2014 in 15 in^3 (250 ml), 60-cell Styroblock™ containers (Beaver Plastics) in an 80:20 peat:perlite medium. Four seed lots, representing four low-elevation seed zones of western Washington, were included in the trial in a randomized complete block design (blocked by seed lot).

Treatments (table 2) were applied with a backpack sprayer to whole Styroblocks™ (60 seedlings) within each seed lot

Table 2. PGR treatments applied to Douglas-fir container seedlings. With the exception of the untreated control, all treatments included the adjuvant Capsil at a rate of 0.10 oz/gal (0.75 g/L).

Treatment	Rate (ppm)	Application method	Number of applications
Control	NA	NA	NA
Bonzi®	50	Spray	One
Bonzi®	50	Spray	Two, 16 days apart
Bonzi®	100	Spray	One
Bonzi®	200	Spray	One
Sumagic®	10	Spray	One
Sumagic®	10	Spray	Two, 16 days apart
Sumagic®	20	Spray	One
Sumagic®	40	Spray	One

NA = not applicable. PGR = plant growth regulator.

(block) July 8, 2014, approximately 5 months after sowing. Spray treatments wetted the foliage just to the point of runoff. Seedling heights were measured every 2 weeks following treatment through the remainder of the growing season. Stem diameters were measured in mid-November at the end of the greenhouse growing season. ANOVA analyses were conducted using the R statistical package (R Core Team 2013). Treatment means were subjected to Tukey's HSD test and considered significantly different at the $p < 0.05$ level.

Results and Discussion

Trial 1: Bonzi® Applications on Red Alder Small Plugs for Transplant

All Bonzi® treatments produced a rapid and pronounced reduction in height growth of red alder plugs. PGR-treated seedlings also had noticeably thicker, darker green leaves with shorter stem internodes and smaller leaf areas (figure 2). Treatments, including the Capsil adjuvant, did not differ from stand-alone treatments and are dropped here for clarity. Four weeks after application, all Bonzi® treatments were significantly shorter than the control (figure 3). In early June (7 weeks after treatment), seedlings were transplanted to a bareroot field. At the time of transplant, significant height differences remained between controls and all other treatments (figure 3). No statistical differences were evident in stem diameter on any date or packout number by treatment (data not shown).

It was surprising that seedlings treated with the drench treatments (5 and 10 ppm) were the first to catch up to control seedlings in height. No significant height differences were evident between drenched and control seedlings by July 24,

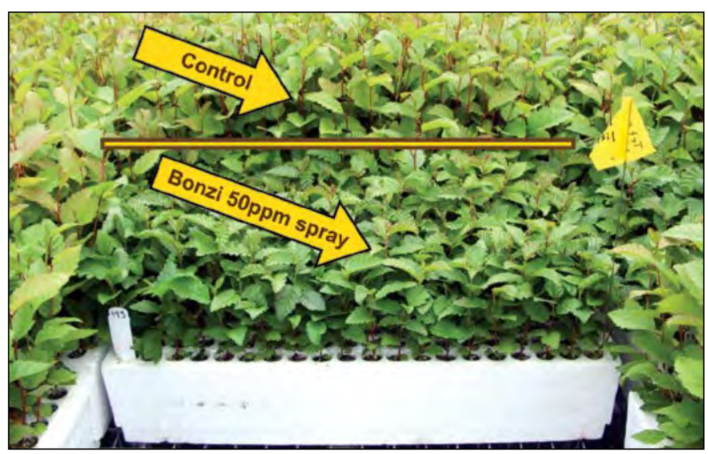


Figure 2. All Bonzi® plant growth regulator (PGR) treatments reduced red alder height growth, shortened internode distance, and decreased leaf area on new leaves before transplant. Leaves were noticeably darker green and thicker than those on the control seedlings. Photo taken 5 weeks after treatment. (Photo by Nabil Khadduri, 2014)

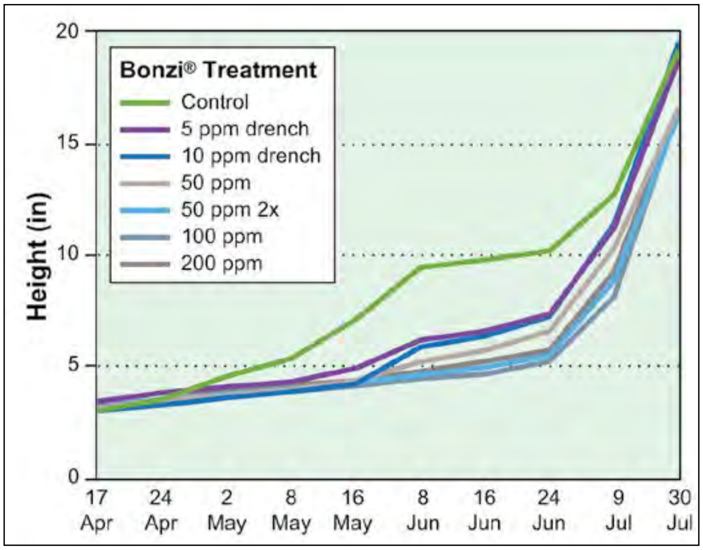


Figure 3. All Bonzi® treatments produced significantly shorter red alder seedlings compared with the control seedlings 4 weeks after application (mid-May) and at transplant (7 weeks after treatment; early June). By late July (14 weeks after treatment, 7 weeks after transplant), seedlings from the spray treatments were still significantly shorter than the control seedlings, but those in the drench treatments no longer differed significantly from the control.

but seedlings treated with spray treatments were still significantly shorter than control seedlings at this time. Even at lower application rates, drench treatments were expected to have a longer lasting effect because of the nature of uptake (Runkle 2012). Growing medium moisture at application was neither dry nor wet (approximately 80 percent gravimetric container weight). During application, there was roughly 10 percent leachate fraction of application volume, which rules out the possibility of overleaching. Perhaps rooting had not fully progressed for adequate uptake at the time of the drench application, resulting in the shorter duration of effect observed after transplanting.

By the end of the growing season (November 7), no significant differences were evident in height among treatments (data not shown). In the bareroot field, all treatments continued to be cultured operationally following mid-season transplant. Because red alder plugs are generally leggy and susceptible to drought stress at this intermediate transplant stage, operational watering for the first several weeks following transplant may have exceeded the needs of the more compact, thicker-leaved, PGR-treated seedlings. Irrigation, therefore, may have played a role in the elimination of treatment differences as the season progressed. Regardless of final morphology at the end of the season, nursery staff found the PGR-treated trees easier to lift and handle during mid-season transplant.

Spring 2015 operational experience demonstrated a cost of 8 cents per Styroblock™ (13.4 by 26.4 in [34.0 x 67.0 cm]) for a 50 ppm Bonzi® spray-to-wet application.

Trial 2: Bonzi® and Sumagic® Applications on Large Douglas-Fir Plugs for Outplant

All Sumagic® rates significantly reduced Douglas-fir seedling height growth (by roughly 25 percent) compared with nontreated control seedlings (figures 4 and 5A). Seedlings treated with Bonzi® consistently trended shorter than the control seedlings, although this effect was not statistically significant (figure 4). While all PGR treatments suppressed stem diameter growth compared with the control, higher rates of Sumagic® suppressed stem diameter growth more than Bonzi® applied at 100 and 200 ppm. Higher rates of Sumagic® suppressed stem diameter growth by roughly 30 percent compared with control seedlings (figure 5B). Only the 10 ppm Sumagic® treatment significantly reduced the seedling sturdiness quotient compared with control seedlings, a 13-percent reduction (figure 5C). In other trials, sturdiness quotients have been more consistently improved with the application of PGRs to Douglas-fir, but these were usually drench treatments (van den Driessche 1988, Wheeler 1987).

We chose to test only Bonzi® (paclobutrazol) and Sumagic® (uniconazole) spray applications on Douglas-fir seedlings because of the relative ease and lower cost of application compared with drench applications. Uniconazole is most effective when applied as a soil drench, because the chemical is best transported throughout the plant via xylem tissue rather than phloem tissue (Duck et al. 2004). It appears that drench treatments hold the greatest promise for reducing late-season growth of Douglas-fir seedlings and will be the focus of future research for this species.

Figure 4. Effect of Sumagic® spray treatments at 20 ppm (on left) compared with untreated control seedlings (on right) 8 weeks after treatment. (Photo by Nabil Khadduri, 2014)

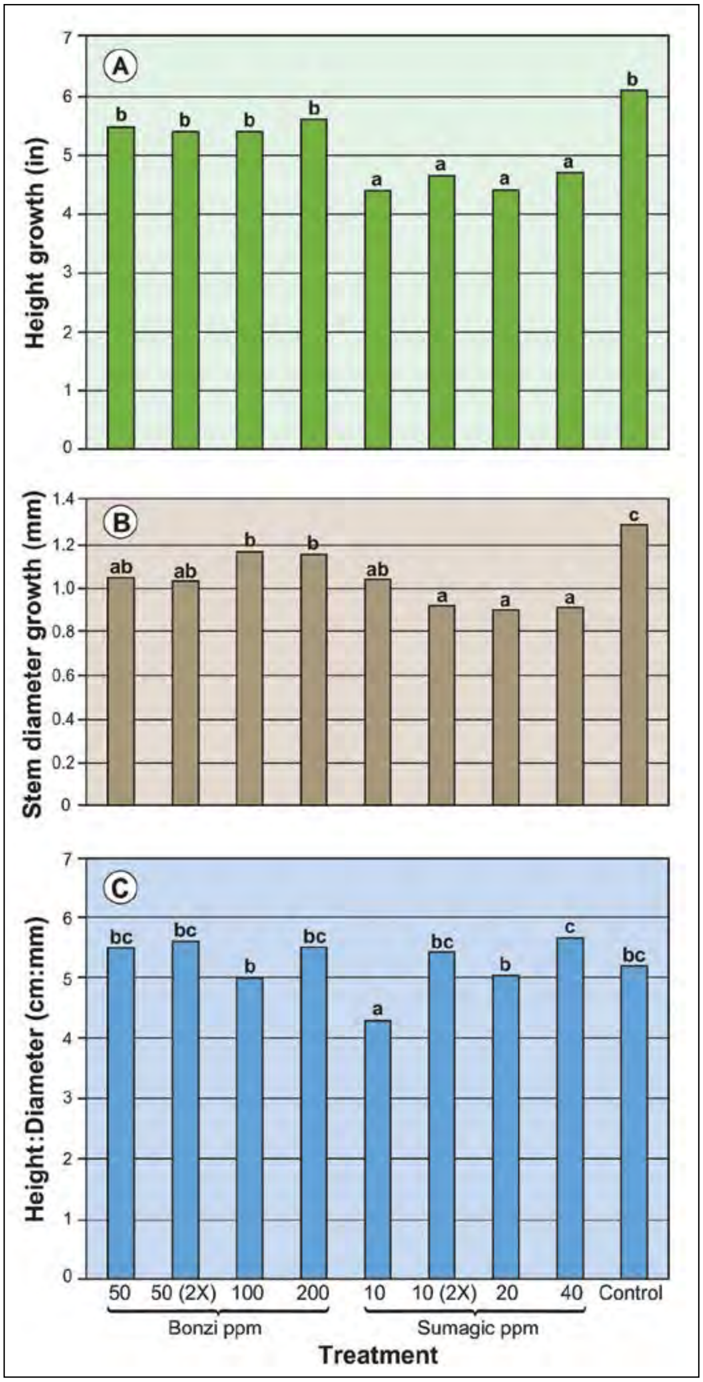


Figure 5. All Sumagic® spray rates significantly reduced height growth in Douglas-fir seedlings compared with those in the Bonzi® and control treatments (A). While all plant growth regulator (PGR) treatments suppressed stem diameter growth compared with the control, higher rates of Sumagic® suppressed stem diameter growth more than Bonzi® applied at 100 and 200 ppm (B). Only seedlings treated with 10 ppm Sumagic® had sturdier (lower height to stem diameter ratio) seedlings compared with the control seedlings. Bars with the same letter do not differ significantly at the $p < 0.05$ level.

Conclusions

Bonzi® effectively reduced early season height growth in red alder seedlings resulting in preferable morphology for operational handling during transplant. Height suppression from drench treatments unexpectedly wore off first, followed by spray treatments as the growing season continued. Both Bonzi® and Sumagic® sprays had a minor effect on Douglas-fir seedling morphology. While Sumagic® sprays reduced seedling height of Douglas-fir more than Bonzi® sprays and controls, these reductions were relatively small and were accompanied by an undesirable decline in stem diameter growth. Only the 10 ppm Sumagic® treatment produced a more balanced height to stem diameter ratio compared with control seedlings.

Because of the limited effect of PGR drenches on red alder and the increased cost of treatment, no drenches were applied to Douglas-fir plugs. In theory, PGR drenches should result in more profound and long-lasting growth regulation effects. Sumagic® drenches, in combination with other shutdown techniques, may yet prove to be an effective strategy in manipulating late-season Douglas-fir growth and will be further examined.

Address correspondence to—

Nabil Khadduri, Nursery Scientist, Webster Forest Nursery WADNR, PO Box 47017, Olympia, WA 98504; e-mail: nabil.khadduri@dnr.wa.gov; phone: 360–902–1279.

Acknowledgments

The author thanks Kila Benge, nursery technician, for her assistance and advice on these trials.

REFERENCES

Currey, C.J.; Lopez, R.G. 2010. Applying plant growth retardants for height control. Purdue Ext. HO-248-W.

Duck, M.W.; Cregg, B.M.; Fernandez, R.T.; Heins, R.D.; Cardoso, F.F. 2004. Controlling growth of tabletop Christmas trees with plant growth retardants. HortTechnology. 14(4): 528–532.

Lattimer, J.G.; Whipker, B. 2012. Selecting and using plant growth regulators on floricultural crops. Blacksburg, VA: Virginia Polytechnic Institute and State University. Pub. 430-102. http://pubs.ext.vt.edu/HORT/HORT-43P/HORT-43P-pdf.pdf. (23 December 2014).

R Core Team. 2013. R: a language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing.

Rietveld, W. 1988. Effect of paclobutrazol on conifer seedling morphology and field performance. In: Landis, T.D., tech. coord. Proceedings, combined meeting of the Western forest nursery associations. Gen. Tech. Rep. RM-167. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 19–23.

Runkle, E. 2012. Successful use of paclobutrazol. In: Greenhouse product news. http://flor.hrt.msu.edu/assets/Uploads/Useofpaclobutrazol.pdf. (23 December 2014).

Runkle, E. 2013. PGR application considerations. In: Greenhouse product news. http://www.gpnmag.com/sites/default/files/14_TechnicallySpeaking_GPN0513 FINAL.pdf. (23 December 2014).

Smith, D.B.; Lloyd, E.; O'Neill, G. 1994. Improving conifer seedling quality with CONFER®. In: Landis, T.D.; Dumroese, R.K., tech. coords. Proceedings, forest and conservation nursery associations. Gen. Tech. Rep. RM-GTR-257. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 281–284.

van den Driessche, R. 1990. Paclobutrazol and triadimefon effects on conifer seedling growth and water relations. Canadian Journal of Forest Research. 20(6): 722–729.

Wheeler, N.C. 1987. Effect of paclobutrazol on Douglas-fir and loblolly pine. Journal of Horticultural Science. 62: 101–106.

The Use of Remote Monitoring and Growing Degree Days for Growing Container Seedlings

T.J. Hodgson

Forest Nursery Consultant, Hodgson Consulting Inc., Coquitlam, British Columbia, Canada

Abstract

A remote monitoring system used in Mexico is described for small nurseries that cannot support full-time, onsite specialist growers. In addition, the concept of Growing Degree Days is described for transferring a growing regime from one site to another untested site. This paper was presented at a joint meeting of the Western Forest and Conservation Nursery Association, the Intermountain Container Seedling Growers Association, and the Intertribal Nursery Council (Boise, ID, September 9–11, 2014).

Introduction

Mexico has more than 600 container forest nurseries. The military (SEDENA) operates the largest nurseries as part of its mission to "…carry out civic actions and social work to support the growth of the country" (Eguiluz-Piedra 2003). SEDENA currently operates 20 forest nurseries, with a total capacity of 60 million seedlings. The biggest nursery has a capacity of 12.5 million seedlings, and the next biggest nursery has a capacity of 7.5 million seedlings (Eguiluz-Piedra 2003). The remaining nurseries are much smaller, averaging production of less than 250,000 seedlings per year.

The Mexican Government's National Forestry Commission—CONAFOR—contracts with nonmilitary community and private nurseries to supply communities with tree seedlings and subsidizes the planting. For political reasons, nursery production is widely dispersed. Therefore, if a private nursery operator aspires to greater production, the only route to accomplishing that is by operating multiple sites.

Very few small nurseries can afford qualified, competent staff. To address this issue and improve nursery management and production, Sistemas Agrotec S.A. de C.V. installed a remote monitoring system at a nursery near Uruapan, Michoacan, Mexico. The Agrotec view is that one skilled manager can monitor several operations from a distance and be ready to intervene. The installation allows for remote monitoring, not remote control (as is available for sophisticated greenhouse operations).

The objective of the installation was to evaluate equipment and procedures to develop a standard operating procedure (SOP) that could be transferred to other (possibly untested) sites to raise seedlings of the same quality in commercial quantities in the first year.

Remote Monitoring

The remote monitoring system was set up in 2012 using a Decagon system (Decagon Devices, Inc., Pullman, WA). The nursery produces 3 million container pine seedlings (*Pinus pseudostrobus* Lindl., *P. michoacana* Martinez, and *P. montezumae* Lamb.) annually for reforestation of community lands.

Sensors

Monitoring electrical conductivity (EC) of leachate is essential in any container nursery operation (Tinus and McDonald 1979), particularly in an outdoor compound, where a growing system with soilless media, multiple-cavity containers, soluble fertilizers, and irrigation patterns are handled by workers with little technical background or knowledge of plant physiology. Monitoring stations were set up to measure EC and irrigation with soluble fertilizer (fertigation). One block (Copperblock® 60/250 ml [15 in^3], Beaver Plastics, Ltd., Alberta, Canada) had its ventilation holes taped closed so that only drainage solution from the root plugs could flow into a large funnel and be measured for EC with the Decagon ES2 EC sensor (figure 1).

The station also monitors other parameters (figure 1): a pressure switch (Decagon PS1 sensor) inserted below an irrigation nozzle monitors whether the irrigation is on or off; a two-blade sensor inserted into one cavity (Decagon EC-5 sensor) monitors the percent moisture content of the growing medium; and a Thermoworks USB Data Logger (Thermoworks, Lindon, UT) monitors under-bench temperature. Block weight is monitored gravimetrically on a domestic scale (figure 1) and manually recorded before and after irrigation (remote monitoring is under development for block weight).

Figure 1. Monitoring station in a *Pinus montezumae* Lamb. seedling crop in Copperblock® 60/250ml (15 in^3; Beaver Plastics Ltd., Alberta, Canada) to measure irrigation, electrical conductivity, block weight, and air temperature. (Photo by Jol Hodgson, 2012)

Datalogging and Monitoring

The Decagon sensors described previously are connected by cable to a Decagon EM50R Datalogger, which is where each sensor can be calibrated and data can be transmitted. Each Decagon EM50R can serve five sensors.

All Decagon sensor data are accumulated in the EM50R Datalogger. Every few minutes, data are transmitted by radio to a central Decagon datastation (figure 2), where it is accumulated. The datastation is connected by cable to a laptop computer running the Decagon DataTrac3 software, which can download on demand and display the data graphically or as a spreadsheet (figure 3).

The laptop in the nursery is accessed from a remote location over the Internet through the LogMeIn program (Boston, MA; http://www.logmein.com). The laptop is located at the nursery under cover to protect it from elements and theft. It is important that the cable also be protected from weed-clearing equipment and other hazards and that the power source and Wi-Fi be monitored regularly to ensure continuous operation. This system provides real-time data monitoring and also displays data for any time period desired. Frequency of monitoring depends on the crop's growth stage, weather conditions, and availability of personnel. The Thermoworks temperature datalogger recording interval is programmed before placement to allow for a full year's recording. Information gathered manually is documented and uploaded to "the Cloud," using Dropbox (http://www.Dropbox.com) for remote access.

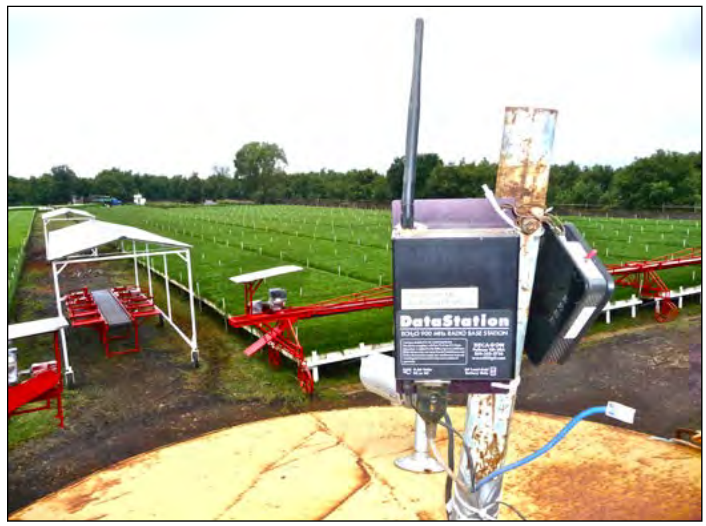


Figure 2. The data station is centrally located and can receive data from several dataloggers. Data are then transmitted to remote computers over the Internet. (Photo by Jol Hodgson, 2012)

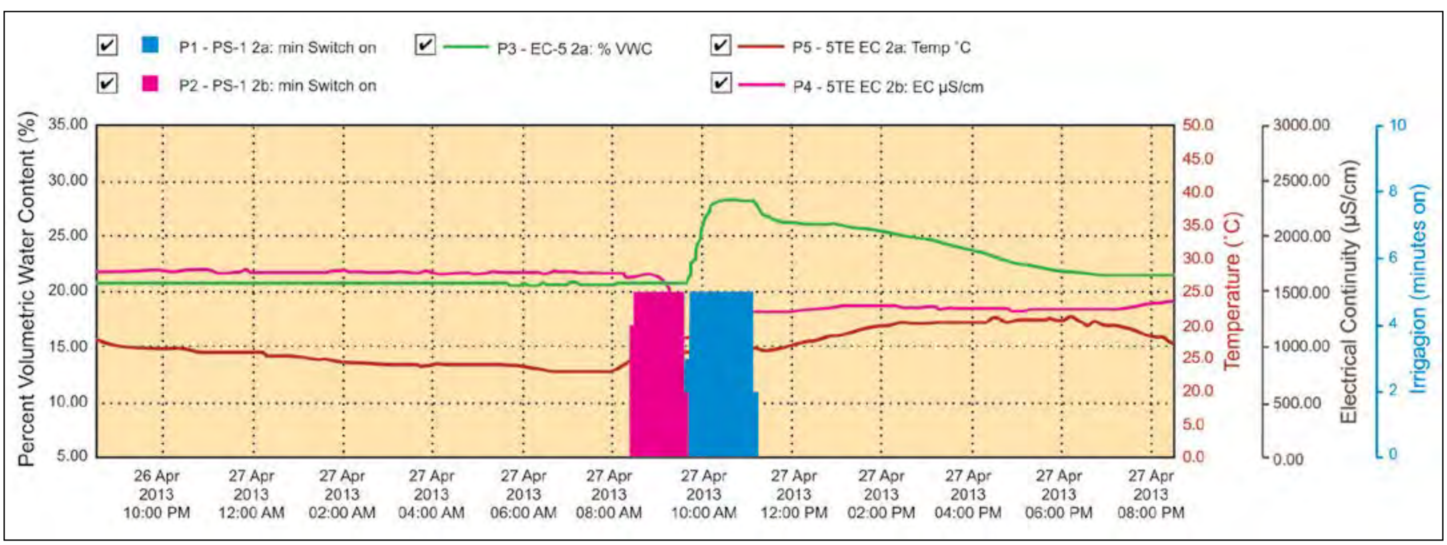


Figure 3. Typical 24-hour graph from remote monitoring includes irrigation duration (pink and blue columns), leachate electrical conductivity (pink line), growing medium moisture content (green line), and under-bench temperature (red line).

Growing Degree Days

Sistemas Agrotec S.A. de C.V. has adopted the target plant concept (Landis et al. 2010) and has developed SOPs (Grossnickle 2011) for *Pinus pseudostrobus* Lindl., *P. michoacana* Martinez, and *P. montezumae* Lamb. These SOPs aim to raise seedlings to approved quality specifications and in a hardened condition by the onset of seasonal rains at the end of May.

Established SOPs can be transferred to an untested nursery location at a higher or lower altitude by converting the growing period to Growing Degree Days (GDDs). GDD is a common parameter in agriculture (Lee 2011) but has been little used in forest nursery operations (Armson and Sadreika 1974, Hodgson 1985). GDD is an assessment of the heat value of each day and can be used to estimate the amount of seasonal growth plants have achieved. GDD is calculated by summing each day's maximum and minimum temperatures, dividing by two, and subtracting a base temperature. The cumulative GDD provides a thermal prediction of plant growth stages (Miller et al. 2001). For the Mexican nurseries in this project, a base temperature of 10 °C (50 °F) was used in the calculation of GDD (determined from the under-bench temperature datalogger) for pine species as related to seedling growth. Figure 4 provides an example of a typical growth curve for *Pinus pseudostrobus* as related to cumulative GDD. The target height for top clipping is 20 cm (8 in); this height is attained at approximately 1,400 GDD, and the SOP requires this stage to be reached by May 1. A sowing date for an untested site can be calculated using these data through retrograde extrapolation based on historical cumulative GDD for that site using local weather records.

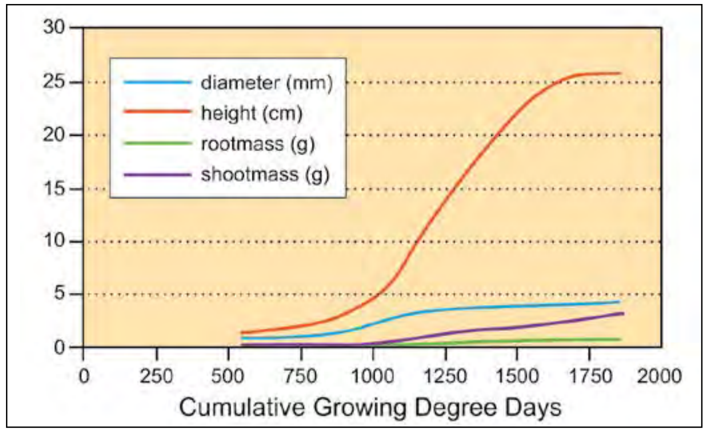


Figure 4. Growth of *Pinus pseudostrobus* seedlings relative to cumulative Growing Degree Days.

Conclusions

Commercially available equipment can be installed in a small forest nursery to provide remote monitoring of growing conditions and fertigation activities. A specialist grower can monitor several nurseries from a great distance. Remote monitoring, however, is no substitute for "eyes-on-the-crop" scouting for pests and diseases, irrigation blockages, inventory and growth measurements, and other nursery management needs.

An SOP for raising target seedlings can be transferred to an untested site at a lower or higher elevation using the GDD formula.

Address correspondence to—

Jol Hodgson, Forest Nursery Consultant, 110-2995 Princess Crescent, Coquitlam, British Columbia, Canada V3B 7N1; e-mail: tjhodgson@shaw.ca; phone: +1–604–833–0620.

REFERENCES

Armson, K.A.; Sadreika, V. 1974. Forest tree nursery soil management and related practices. Ottawa, Ontario, Canada: Ministry of Natural Resources, Division of Forests, Forest Management Branch. 177 p.

Eguiluz-Piedra, T. 2003. FAO advisory committee on paper and wood products—forty-fourth session. Oaxaca, Mexico. http://www.fao.org/docrep/006/y4829e/y4829e09.htm. (15 August 2014).

Grossnickle, S.C. 2011. Tissue culture of conifer seedlings—20 years on: viewed through the lens of seedling quality. In: Riley, L.E.; Haase, D.L.; Pinto, J.R., tech. coords. National proceedings, forest and conservation nursery associations—2010. Proc. RMRS-P-65. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 139–146.

Hodgson, T.J. 1985. Heat unit summation theory in commercial nursery management. In: South, D.B., ed. Proceedings, international symposium on nursery management practices for the southern pines. Auburn, AL: Auburn University: 64–71.

Landis, T.D.; Dumroese, R.K.; Haase, D.L. 2010. Seedling processing, storage, and outplanting. Vol. 7. The container tree nursery manual. Agriculture Handbook 674. Washington, DC: U.S. Department of Agriculture, Forest Service. 200 p.

Lee, C. 2011. Corn growth stages and growing degree days: a quick reference guide. AGR 202. Lexington, KY: Cooperative Extension Service, University of Kentucky, College of Agriculture. http://www2.ca.uky.edu/agc/pubs/agr/agr202/agr202.pdf. (August 2014).

Miller, P.; Lanier, W.; Brandt, S. 2001. Using growing degree days to predict plant stages. MT2001103 AG. Missoula, MT: Montana State University Extension Service. 8 p.

Tinus, R.W.; McDonald, S.E. 1979. How to grow tree seedlings in containers in greenhouses. Gen. Tech. Rep. RM-60. Washington, DC: U.S. Department of Agriculture, Forest Service. 256 p.

Recent Work at the National Seed Laboratory on Seed Storage, Upgrading Native Plant Seed Germination, and Germination Protocols for New Species

Robert P. Karrfalt

Director, National Seed Laboratory, U.S. Department of Agriculture, Forest Service, Dry Branch, GA

Abstract

Equilibrium relative humidity is an excellent emerging technology for managing seed moisture for storage purposes. This article describes how this technology is improving seed storage and some pitfalls to avoid in using this technology. Native plant seeds are often of lower quality than needed for efficient nursery production of seedlings or the application of advanced seed-sowing technologies such as seed pelletizing. Work on Wyoming big sagebrush (*Artemisia tridentate* Nutt. spp. *wyomingensis* Beetle & Young) indicates that upgrading technologies used successfully in forestry will also produce better seed lots with other native plants. This paper was presented at a joint meeting of the Western Forest and Conservation Nursery Association, the Intermountain Container Seedling Growers Association, and the Intertribal Nursery Council (Boise, ID, September 9–11, 2014).

Introduction

Most native plants are regenerated from seeds. Therefore, a reliable supply of good-quality seeds is needed for restoration and maintenance of many plant communities. Storing seeds until needed and using them efficiently are two important capabilities in achieving a reliable seed supply. The demand for seeds can vary greatly and unpredictably from year to year. Supplying such an unpredictable need can be very problematic because seeds are usually not available every year in the wild and seed production in cultivated fields requires years of advanced planning. Long-term seed storage, however, can help solve the problem by acquiring seeds when available and keeping them alive until needed. Another important factor in increasing seed supply is using available supplies efficiently, which generally requires upgrading seed qualities to high levels. This article summarizes some recent work at the U.S. Department of Agriculture (USDA), Forest Service, National Seed Laboratory (NSL) in Dry Branch, GA, on preparing seeds for storage and improving seed quality and performance.

Managing Seed Moisture for Seed Storage With Equilibrium Relative Humidity

Moisture is the most critical factor in seed storage. The most advanced methods for assessing seed moisture status is equilibrium relative humidity (ERH; Baldet et al. 2009, Karrfalt 2014; figure 1). ERH is fast (producing an answer in about 5 minutes), nondestructive, and universally applicable to all orthodox seeds at any state, from raw harvested seeds to the finished cleaned seed lot. In addition, this method is economical because it uses very little energy compared with oven methods and can be measured with a relatively low-cost hygrometer. Working with the ERH test at NSL has led to a better understanding of managing seed moisture as described in the following sections.

Figure 1. Equilibrium relative humidity of seeds being measured with a hygrometer. (Photo by R.P. Karrfalt, 2012)

Refining Seed Storage Recommendations

A longstanding view of orthodox seeds is that if they are dried to any moisture level between 6 and 9 percent (an ERH of 50 percent or less) and stored at any temperature below freezing, no viability will be lost for at least 10 years. This view was based on experience with conifer species and a handful of hardwood species in which it held true. A recent study of Wyoming big sagebrush (*Artemisia tridentate* Nutt. spp. *wyomingensis* Beetle & Young) seeds (Karrfalt and Shaw 2013), however, found that such a generalized prescription did not work. Drying the seeds to an ERH of 30 percent was found to be the best practice for freezer storage. A target ERH of 40 percent was also found to be acceptable, but this level required using -20.0 °C (-4.0 °F) for the storage temperature, whereas, at 30 percent ERH, either -8.0 °C or -20.0 °C (17.6 °F or -4.0 °F) could be used to store seeds for at least 5 years. The prescription for seed storage needs to be more specific for sagebrush; this approach is likely the case for other native species as well.

Obtaining Accurate Equilibrium Humidity Readings

A key factor in using ERH for seed moisture testing is making sure that the seeds are at equilibrium. In working with this test at NSL, we have observed that false readings sometimes occurred with larger seeds or a rapid rate of drying. Based on these observations, trials were conducted to examine the role of the following factors in reaching equilibrium: seed size, drying rate, and seed coat thickness. Dogwood (*Cornus florida* L.) and river birch (*Betula nigra* L.) were tested because they differed greatly in their physical characteristics. Dogwood seeds are much larger than river birch seeds and have a thick, stony seed coat while river birch seeds have a thin, papery seed coat. Initial ERH for both species was approximately 60 percent. Two drying regimes were used: an aggressive rate consisting of a small seed sample placed with a large amount of a chemical desiccant and a slower rate in which the seeds were air dried at 31 to 34 percent relative humidity. Three drying periods were used: 8, 19, and 32 hr. One seed lot per species was used, and it was divided into equal portions using a riffle divider and one fraction assigned to each of the six drying treatments. ERH was measured immediately at the end of the drying period and at three subsequent times until the change in reading was only 1 or 2 percent and, therefore, the seeds were judged to be at equilibrium. The first subsequent reading was taken 1 to 2 hr after drying, the second at 22 to 26 hr, and the final at 38 to 46 hr. The interval between the initial reading and the subsequent readings varied because no readings were taken during night time hours. Samples were kept in sealed containers between ERH measurements so that there was no moisture loss or gain.

The small river birch seeds with their thin seed coats were at equilibrium at the initial reading and completely dried with all drying periods. For the rapidly dried, larger seeded dogwood, the difference between initial reading and the reading taken 1 to 2 hr later was 8 to 10 percent. The difference between the second and third readings was 3 to 4 percent, and between the third and the fourth readings was 0 to 1 percent. This difference indicates that an accurate ERH reading for a sample of a larger seeded species that had been dried rapidly required holding the seeds for about 24 hr past the cessation of drying. The same pattern was observed in the slow drying regime but the differences among successive readings were never more than 3 percent, meaning that initial readings are close to true equilibrium and a usable reading might be taken sooner than 24 hr after cessation of drying. Length of drying did not appear to create any bias in the readings on dogwood seeds although the longer drying period removed more moisture from the seeds than the shorter periods.

In conclusion, the larger seeds, when dried aggressively with the calcium sulfate, gave highly biased ERH readings immediately following the cessation of drying. Drying with air at 10- or 15-percent relative humidity would very likely produce the same effect as using the calcium sulfate drying method. The most likely explanation for this bias is that moisture was rapidly pulled from surface layers of the seed faster than moisture closer to the center of the seed could diffuse to the surface layers. The ERH reading was of the surface layers of the seed and not the whole seed. By holding the seeds for 24 hr, the moisture content in the inner and surface layers of the seed equilibrated and ERH readings were then representative of the entire seed, not just the surface layers. In slower drying regimes, the inner seed moisture was able to diffuse to the surface layers at close to the same rate that moisture was removed from the surface; therefore, the bias was much smaller. This internal seed moisture gradient did not develop in small seeds, resulting in accurate readings immediately at the cessation of drying. The safest approach, especially with an unfamiliar species, would be to check the ERH 24 hr after the initial reading to be sure the ERH readings are not biased and the moisture level is low enough for safe storage.

Upgrading Native Seed Quality

High-quality seeds are needed in any native plant restoration work, and the larger the project, the more important this attribute becomes. Germination especially has a major effect on restoration costs and effectiveness. In container seedling nurseries, better germination means fewer seeds must be sown per cavity, and ideally it would be just one seed per cavity for the most cost-effective and genetically sound nursery program. Multiple seeds per cavities incur thinning costs, higher seed costs, and wasted seeds because of discarded seedlings. Even if seedlings are not discarded, transplanting adds cost. Direct seeding is often problematic because of the small seed size of many native plants. Pelletizing small seeds would be a great benefit to both direct seeding and nursery sowing because a pellet can be made larger and uniform in size for easy handling (Khadduri 2007). Only seeds of high purity and germination are economically suitable for pelletizing, however, because pelletizing is an expensive process. Sizing seeds with screens followed by weight separation has worked to upgrade conifer seed lots and can also be applied to other smaller seeded native plant seeds. Wyoming big sagebrush is one example.

Upgrading Wyoming Big Sagebrush Seed

Five seed lots of Wyoming big sagebrush were acquired from the Bureau of Land Management seed warehouse (Boise, ID). These seed lots were approximately 9 months from harvest at the time of this experiment. Initial cleaning with an aspirator removed the lightest trash and reduced the volume of material by 50 percent. The seeds were then scalped with 22 by 22 woven wire screen. The numbers of a woven wire screen indicate how many wires there are per inch (2.54 cm). A 22 by 22 screen has 22 parallel evenly spaced wires per inch (2.54 cm) going from one side to the other and 22 parallel evenly spaced wires per inch (2.54 cm) that are perpendicular to the first set of wires. Therefore, a smaller number represents a larger screen hole. The seeds were further divided into nine sizes using eight screens ranging in size from 24 by 24 to 38 by 38 using only even-numbered screens. Seed size was labeled in this manner. For example, a number 24 seed passed through the 22 by 22 screen but did not pass through the 24 by 24 screen. In like manner, a 26 seed passed through the 24 by 24 screen but not the 26 by 26 screen, and so forth for all seed sizes.

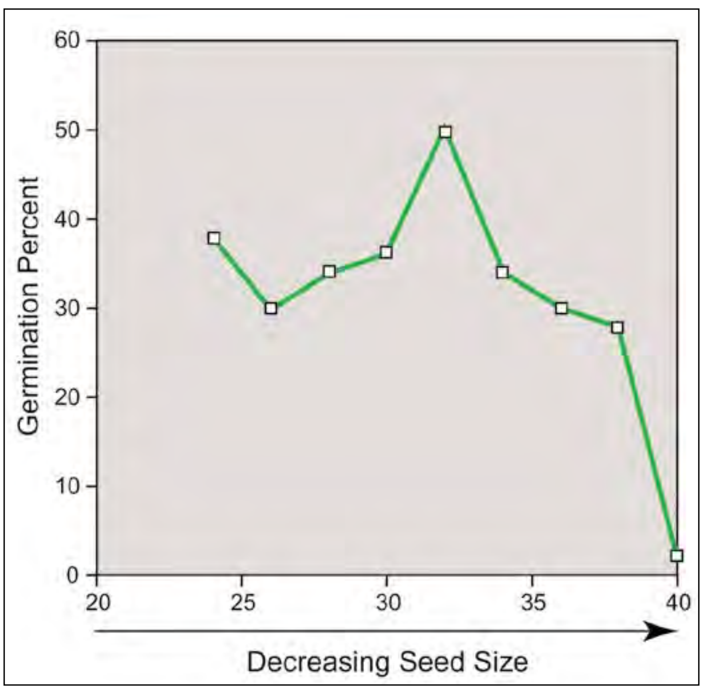


Figure 2. Effect of seed sizing on germination of *Artemesia tridentata* var. *wyomingensis.*

Fifty seeds from each size fraction were germinated at 15 °C (59 °F), and germination was counted at 7 days (figure 2). In this trial, most seeds had similar germination, with the exception of the smallest seeds (passing through the 38 by 38 screen), which did not germinate and should be discarded; these small seeds are likely immature or sterile. Among the remaining sizes, the larger the seed, the larger the 7-day-old seedling tended to be (figure 3). Seedling size differences such as these can have implications on the genetic diversity of the crop, seedling-to-seed ratios, and required cultural practices. These results indicate that native plant seed quality and performance can be improved by discarding smaller seeds to raise nursery efficiency and prepare seeds for advanced sowing technologies. Further trials on seed sizing of sagebrush seeds and seeds of other species, therefore, are warranted.

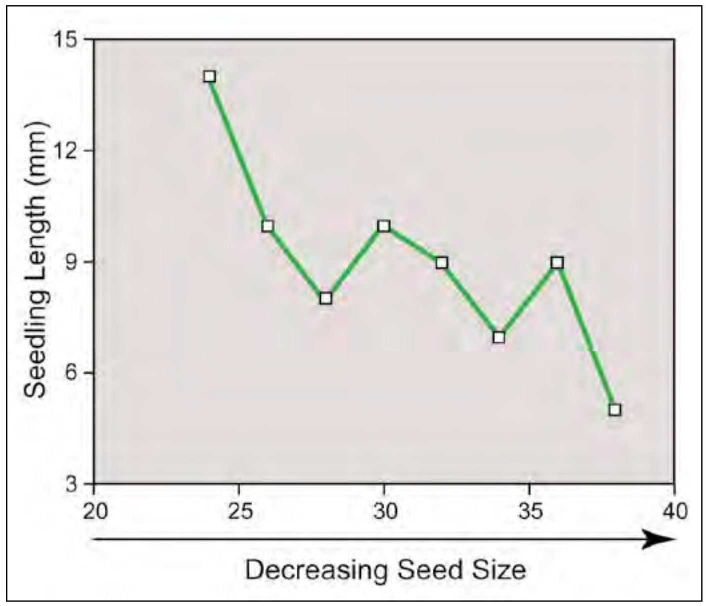


Figure 3. Effect of seed sizing on 7-day-old seedlings of *Artemesia tridentata* var. *wyomingensis.*

Equipment for Upgrading Seeds

The aspirator used to upgrade the sagebrush seeds was constructed from PVC (polyvinyl chloride) drainpipe for approximately $100. If a vibratory feeder, such as shown in figure 4, is used, the cost increases to about $600. Despite its low cost, the aspirator is very precise at cleaning seeds of a wide range of sizes from pine (*Pinus* spp.) to sagebrush. The aspirator is one of several inexpensive devices being developed at the NSL to meet the needs of small seeds and restoration operations that generally cannot afford an expensive set of commercially available machines but still need to produce high-quality seeds.

Figure 4. Seed aspirator constructed from PVC (polyvinyl chloride) drainpipe. (Photo by R.P. Karrfalt, 2014)

Developing Germination Protocols

NSL is developing germination protocols for several native species. The process begins by placing seeds in germination chambers programmed to provide four controlled constant temperatures: 10, 15, 20, and 25 °C (50, 59, 68, and 77 °F). Native plant seeds (either not stratified or stratified at 3 °C [37 °F] for 30 days) are tested for germination in each temperature. Longer stratification periods might be used in subsequent tests when dormancy is found. This process gives a total of eight germination tests in the initial screening for determining an optimum germination temperature and the presence of dormancy. Followup tests are conducted using the best temperature(s) and those alternating temperatures close to the best temperature(s). Requests for the development of germination protocols can be submitted to the NSL. Seeds must be supplied to the laboratory for this research.

Address correspondence to—

Robert P. Karrfalt, Director, National Seed Laboratory, U.S. Department of Agriculture, Forest Service, 5675 Riggins Road, Dry Branch, GA 31020; e-mail: rkarrfalt@fs.fed.us; phone: 478–751–3551.

REFERENCES

Baldet, P.; Colas, F.; Bettez, M. 2009. Water activity: an efficient tool for seed testing. Tree Seed Working Group News Bulletin. 50: 15–17.

Karrfalt, R.P. 2014. Assembling seed moisture testers, seed dryers, and cone dryers from repurposed components. Tree Planters Notes. 57(2): 11–17.

Karrfalt, R.P.; Shaw, N. 2013. Banking Wyoming big sagebrush seeds. Native Plants Journal. 14(1): 60–69.

Khadduri, N. 2007. Greenhouse germination trials of pelletized western redcedar and red alder seeds. In: Riley, L.E.; Dumroese, R.K.; Landis, T.D., tech. coords. National proceedings, forest and conservation nursery associations—2006. Proc. RMRS-P-50. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 15–19.