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# National Proceedings: Forest and Conservation Nursery Associations – 2011



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## Abstract

These proceedings are a compilation of 20 papers that were presented at the regional meetings of the forest and conservation nursery associations and the Intertribal Nursery Council meeting in the United States in 2011. The **Joint Meeting of the Southern Forest Nursery Association and Northeastern Forest and Conservation Nursery Association** was held at the Pullman Plaza Hotel, Huntington, WV, July 25 to 28, 2011. Subject matter for the technical sessions included history and current status of tree planting and nursery production, mine reclamation research and implementation, American chestnut restoration, and soil fumigation regulations and alternatives. Field trips included afternoon tours of the Kentucky Division of Forestry's Morgan County Tree Nursery in West Liberty, KY, and a mining site near Dunlow, Wayne County, WV. The **Annual Meeting of the Western Forest and Conservation Nursery Association** was held at the Hilton Garden Inn Cherry Creek in Denver, CO on August 16 to 18, 2011. Subject matter for the technical sessions included development of local genotypes for native plants, marketing strategies, nursery techniques and products, restoration strategies, insect and disease management, and nursery phytosanitation. Afternoon field trips included tours of Denver Botanic Gardens and the Rocky Mountain Arsenal National Wildlife Refuge, both in Denver, CO. The **Intertribal Nursery Council Meeting** was held at the Pechanga Casino, Temecula, CA on September 12 to 15, 2011. The meeting was hosted by the Pechanga Band of Luiseño Indians and USDA Forest Service. Subject matter for the technical sessions included propagation strategies for culturally important plant species, collaboration for conservation and education, seedling storage, and seed viability. Two short workshops on growing media and containers were also given. Field trips included an afternoon tour of the Pechanga Native Plant Nursery, with optional concurrent tours of the Cultural Resources Department, the Great Oak Tree, and the Cove Village. Additionally, there was an all-day field trip with tours of Mockingbird Nurseries, Inc., Indian Canyons - Agua Caliente Band of Cahuilla Indians, Santa Rosa and San Jacinto Mountains National Monument Visitor Center, and the Palms to Pines Scenic Highway.

**Key Words**—bareroot nursery, container nursery, nursery practices, fertilization, pesticides, seeds, reforestation, restoration, tree physiology, hardwood species, native species

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# National Proceedings: Forest and Conservation Nursery Associations—2011

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## Searchable Internet Database—[www.rngr.net](http://www.rngr.net)

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

Huntington, West Virginia

July 25 to 28, 2011



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

*Illustration courtesy of College of Natural Resources, University of Idaho*

# A History of Tree Planting in West Virginia

Kenneth L Carvell

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Carvell KL. 2012. A history of tree planting in West Virginia. In: Haase DL, Pinto JR, Riley LE, technical coordinators. National Proceedings: Forest and Conservation Nursery Associations—2011. Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. Proceedings RMRS-P-68. 3-6. Available at: [http://www.fs.fed.us/rm/pubs/rmrs\\_p068.html](http://www.fs.fed.us/rm/pubs/rmrs_p068.html)

**Keywords:** non-native species, Weeks Act, Knutson-Vandenberg Act, Civilian Conservation Corps, Christmas tree growers, mine reclamation

## Introduction

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West Virginia has often been described by botanists as “the most southern of the northern states, the most northern of the southern states, the most eastern of the western states, and the most western of the eastern states.” Truly, West Virginia, “the Mountain State,” is the cross roads for many species of trees and herbaceous vegetation, and even today we are often surprised by what we find surviving in remote and unique environments.

## Early Planting of Non-Native Tree Species

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### Bald Cypress

I first want to tell a few of my early experiences as a New Englander coming to West Virginia in 1953. I was immediately impressed that Morgantown had 5 large, old bald cypress trees (*Taxodium distichum* [L.] Rich.) in the downtown area. Later, I observed old bald cypress trees in Fairmont and even in Beckley. Curious as to how they got there, at least 320 km (200 mi) north of their natural range, I used an increment borer to determine their age because they all appeared of equal size. My counts showed that they dated from the early 1890s. After asking elderly Morgantowners

how they got their cypress and learning nothing, I turned to reading old newspapers on microfilm. This was a time-consuming type of research, but I found my answer. In 1893, there was a World's Fair in Chicago, the Columbian Exposition. The railroads made it easy to attend because you could buy your ticket at their stations and, as a package deal, get your hotel reservations, transportation fee, and entrance fee to the fairgrounds. In one section of a 1893 newspaper was the sentence, "I watched the crowd getting off the train from the World's Fair, each with their potted cypress clutched in their hand." Evidently all who visited the Louisiana pavilion got a cypress to bring to their hometown.

## Japanese White Pine

Soon after I arrived at West Virginia University, I began receiving pressed specimens of tree foliage that had been sent to the President's Office by people from throughout the State who wanted some unknown tree identified. Every so often I would get a specimen of white pine foliage from southern and southwestern counties. There was always the same statement: this white pine grows as a shade tree in front of our farm house. The pine had a variable number of needles in a cluster, and often only one. I had a key to white pines of the world, and it would invariably key down to Japanese white pine (*Pinus parviflora* Siebold & Zucc.). This was the tree identity I sent to them; however, I always felt uncomfortable about my message. Where would rural West Virginians get a Japanese white pine seedling in 1890 or 1900? Further inquiry, however, substantiated my identification. I learned that Ohio was heavily settled before much of West Virginia was even explored. Ohio had tree nurseries at an early date. Since they had to plant tree seeds that were available on the international market, Japanese white pine was one of their crops. Peddlers came southeast from Ohio into southern West Virginia. In addition to their customary cargo, they often had tree seedlings for ornamental planting. The two most popular were Norway spruce (*Picea abies* (L.) Karst.) and Japanese white pine.

## European Larch and Norway Spruce

The earliest commercial tree planting in West Virginia was done in 1906 to 1907 in Pocahontas County. Here, the George Craig and Sons Lumber Company had extensive land holdings of spruce-northern hardwood mixtures. To make sure that their cutover areas came back to species of value, they hired a forester in 1906 from the Yale School of Forestry. This energetic and colorful German was Max Rothkugel. In 1906, he ordered European larch (*Larix decidua* Mill.) and Norway spruce seeds from European dealers. These were planted in 1907 by scalping 0.3 m (1 ft) diameter areas and placing a few seeds in each spot. Most of these survived on land later acquired by the USDA Forest Service for the future Monongahela National Forest and are still thriving today, with many larch and spruce of magnificent size. This plantation, along a main road, is appropriately marked as the "Rothkugel Plantation" and described by an impressive sign. Today, we know all the details of this unique planting (Rothkugel 1908).

## The Big Stimulus

### The Weeks Act

In 1911, Congress passed the Weeks Act that was signed by President Taft on 1 March 1911. This Act authorized the Federal Government to purchase those forest lands needed to protect the headwaters and flow of navigable streams. This law formed the

basis for establishing National Forests in the eastern United States. Equally important, Federal-State cooperation in wildfire control was authorized. West Virginia was one of the first southern states to qualify by passing enabling legislation for establishing National Forest reserves.

When the Weeks Act was being considered by Congress, it was understood that some of the first Purchase Areas would be established in West Virginia because concerns from the frequent flooding in Pittsburgh had been a strong force in passing this Act.

In the high mountain counties in West Virginia, red spruce (*Picea rubens* Sarg.) was a primary species being logged. These sites had invariably burned after they were clearcut. After repeated burns, most of the thick organic soil had been destroyed and the primary plant cover was pin cherry (*Prunus pensylvanica* L. f.), bigtooth aspen (*Populus grandidentata* Michx.), and a dense ground cover of eastern hayscented fern (*Dennstaedtia punctilobula* (Michx.) T. Moore) and western braken fern (*Pteridium aquilinum* (L.) Kuhn). Even where spruce seeds reached such an area, seedlings had little chance of surviving amidst this aggressive ground cover.

After the boundaries of the Monongahela National Forest were formed through land purchase, a major goal was to "reestablish red spruce on every acre formerly supporting these magnificent stands." Outplantings made on such sites in the 1920s usually failed. Red spruce seedlings outplanted on these sites were invariably smothered by the heavy shade of the vegetative cover. If a small spruce happened to survive such competition, it was often flattened by falling dead ferns being weighed down by the first snows. First year survival counts were often only 5% to 10% at best. It was soon learned, however, that Norway spruce and red pine (*Pinus resinosa* Aiton) could survive the harsh climate on these altered sites, survive in the badly eroded soils, and resist the weight of the falling fern cover.

## Knutson-Vandenberg Act

In 1928, the Knutson-Vandenberg Act sped up the rate of outplanting on National Forest lands. It provided for a certain percentage of timber sale revenues to be retained on the district and used for timber stand improvement activities that included outplanting wherever needed. This Act was eventually broadened in interpretation to designate a certain percentage of all monies from timber sales into a general KV Fund to be used where most needed.

Very little outplanting of red spruce occurred over the next 80 years after the initial outplantings in the 1920s. Norway spruce seeds were far less expensive, seedlings survived and competed much better, and the lumber from Norway spruce and red spruce was of equal value. Since 2000, however, there has been renewed interest in reestablishing red spruce in many areas of West Virginia. Larger seedlings (3+0 and 4+0 stocktypes) show much higher survival rates. Although this stock is expensive, groups such as The West Virginia Highlands Conservancy have been establishing test outplantings with some degree of success.

I always tell my students that if it is pole- or timber-size planted spruce, and someone asks whether it is red or Norway, always say Norway since so few areas were actually planted successfully with red!

## The Civilian Conservation Corps Tree Planting Program

The act establishing the Civilian Conservation Corps (CCC) was passed in March 1933, and by early April a tent camp was operating on the now George Washington National Forest. West Virginia had

68 CCC camps operating at one time or another, and tree planting was a strong part of their program. They relied heavily on Norway spruce for plantings above 975 m (3200 ft) and many of these survived well. With the original topsoil layers gone from years of logging, erosion, and wildfire, they often had to plant two or three buckets of soil with each tree. In spite of the obstacles, many CCC spruce plantations are still thriving. In addition to spruce, they planted large areas of high elevation land with red pine. Eastern white pine (*Pinus strobus* L.) was also a popular species.

Perhaps the most noted of the white pine plantations planted by the CCC is the one at Clover Lick, near Parsons, WV. A Journal of Forestry article described this stand at 25 years of age as putting on over 27 m<sup>3</sup> of new volume growth per hectare per year (3 cords per acre per year) at that time (Yawney and Trimble 1958). Research into the seed source of this plantation showed that the seeds were from Buncombe County, North Carolina. This source starts growing earlier in the season than native white pine, and benefits from being planted in deep, rich alluvial soil.

Little consideration was given at that time to seed source. Much open land was planted with red pine that was favored because it had no natural disease or insect enemies. Many of these plantings have done extremely well even though most of the planting stock came from nurseries in Michigan and Wisconsin. There was such a high demand for seedlings during the CCC years that they were pleased just to get all of the outplanting stock they needed without consideration of seed source. It is interesting to note that red pine is actually native in parts of West Virginia, but there are also isolated colonies persisting in the Eastern Panhandle well south of this pine's main range.

## Peak Planting Years

The late 1940s through mid-1960s were busy years for tree planting in West Virginia. During the 1930s and 1940s, much farm land was abandoned. Although smaller areas seeded in naturally with hardwoods or conifers, many larger areas had inadequate amounts of tree seeds to cover the entire area. Such areas needed to be planted because most had seeded-in with low-value, bird-disseminated species. During this period, production at the State-managed Parsons Tree Nursery (Parsons, WV) reached its peak. Most of the seedlings produced were eastern white pine, Scots pine (*Pinus sylvestris* L.), Norway spruce, and tuliptree (*Liriodendron tulipifera* L.). In addition, there was an increasing demand for black locust (*Robinia pseudoacacia* L.) to be used in reclaiming strip mines.

In the 1950s, demand developed for species for Christmas tree growers. Although their initial demands were largely for Scots pine, eastern white pine, and red pine, growers soon learned that the popular seed sources of Scots pine for timber production did not retain a desirable green color in the late fall and winter. This reemphasized the need for attention to seed source with all conifer species. The state tree nurseries began buying seeds from the French Limoges area and other southern European sources. It is interesting that privately-owned nurseries gradually sprang up that catered primarily to Christmas tree growers, and growers quickly learned that it paid to buy special seed sources and use nonnative species such as Douglas-fir (*Pseudotsuga menziesii* Mirb. Franco), Black Hills white spruce (*Picea glauca* (Moench) Voss var. *densata* L.H. Bailey), white fir (*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.), and other non-native spruce and fir species. Christmas tree growers even bought older transplants at much higher costs than state nurseries charged. They justified these expenses because growers had learned that appearance, not price, was the basic consideration when selecting the family Christmas tree.

During the 1940s and 1950s, various private pulp and paper companies and saw mill owners also became active in planting open lands. Westvaco had amassed large acreages in the Eastern Panhandle and in west central West Virginia. They outplanted not only Virginia pine (*Pinus virginiana* Mill.) and eastern white pine, but also loblolly pine (*Pinus taeda* L.), shortleaf pine (*Pinus echinata* Mill.), and Pitch-Lob hybrids on old field sites. Many of these seedlings were grown at state-owned nurseries at Westvaco's request and expense.

## Clements Tree Nursery Established

Realizing that the high elevation of the tree nursery near Parsons was a disadvantage in many ways, West Virginia bought a large tract along the Ohio River at Lakin in Mason County in the early 1960s and established the Clements Tree Nursery (West Columbia, WV). By 1964, they were shipping trees from this nursery. The earlier spring weather at this location made it possible to start lifting tree seedlings at least a month earlier than was possible at the Parsons Nursery. Foresters, anxious to get their spring planting done as early as possible to assure good survival, had urged the State Department of Natural Resources to acquire this second nursery site. The Clements Tree Nursery is still in operation today.

## Critical Research

The West Virginia University Division of Forestry increased its research in revegetating strip mines and in Christmas tree growing during the 1960s. One study showed that black locust outplanted on excessively regraded strip mines usually had poorer survival and growth than those planted on other strip mines due to extremely compact soils.

Many exotic spruce and fir species were planted on a trial basis on Christmas tree growers' lands throughout the State. At their meetings, it was not unusual to hear them discuss their preference for Serbian spruce (*Picea omorika* (Pancic) Purk.), Nikko fir (*Abies homolepis* Siebold & Zucc.), or Siberian-strain Scots pine. Much of this significant research was done by Dr James Brown, who at that time was on the Forestry staff of West Virginia University.

## Discovery of the Canaan Strain of Balsam Fir

For Christmas tree growers, the isolated pockets of balsam fir scattered throughout the mountains of West Virginia were found to have many favorable characteristics over more northern balsam. Canaan fir (*Abies balsamea* [L.] Mill. var. *phanerolepis* Fernald), as it is called today, had long been known locally as "blister pine," and locations of the scattered wet sites where it occurred were easy to spot because they were marked on early geodetic maps by such names as "blister run swamp" or "blister pine swamp." During the 1960s, Christmas tree growers recognized its virtues of better needle retention, increased contrast between light and dark green foliage color, and good growth at lower elevations.

Although many areas where Canaan fir occurs naturally have been affected by the woolly aphid, seeds have been collected from these locations, and are now being grown and planted extensively over areas in the Northeast. In my visits to New Hampshire, I run into friends who grow Christmas trees, and they are quick to tell me that they are growing Canaan fir from West Virginia. When I tell them that the correct pronunciation is with an accent on the last syllable, they give me this weird look, assure me that they are correct, and move on.

## Summary ---

Clearly, West Virginia has had a rich and varied past with regard to harvest, tree species planted, development of Christmas tree plantations, and associated research. This diverse history has a significant influence on current forest composition and has provided a wealth of information for future forest practices in the State.

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# Historical Periods of Tree Planting in the South

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Hernandez G. 2012. Historical periods of tree planting in the South. In: Haase DL, Pinto JR, Riley LE, technical coordinators. National Proceedings: Forest and Conservation Nursery Associations—2011. Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. Proceedings RMRS-P-68. 7-9. Available at: [http://www.fs.fed.us/rm/pubs/rmrs\\_p068.html](http://www.fs.fed.us/rm/pubs/rmrs_p068.html)

**Abstract:** From 1932 to 2011, 4 distinct periods of tree planting characterized the history of state nurseries in the South. These periods were associated with 4 major programs: the Civilian Conservation Corps, the Soil Bank program, the Conservation Reserve Program, and the expanded Conservation Reserve Program. Throughout these programs, state nurseries fluctuated in numbers and seedling production. The later conservation reserve programs also had an impact on species diversity, including increasing hardwood seedling production.

## Introduction

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Since 1925, trends in seedling production and planting have seen a steady increase to a peak in 1989, followed by a steady decline to present day. Within this time period, 4 distinct periods in production and planting are visible, each corresponding to 4 major federal programs advocating tree planting across the landscape (Figure 1). These programs include the Civilian Conservation Corps (CCC), the Soil Bank program, the Conservation Reserve Program (CRP), and the expanded Conservation Reserve Program (CRP2). While forest industry had a large part in creating the bulk of the trends, the non-industrial private land owners participating in the Conservation Reserve Programs also had a big influence.

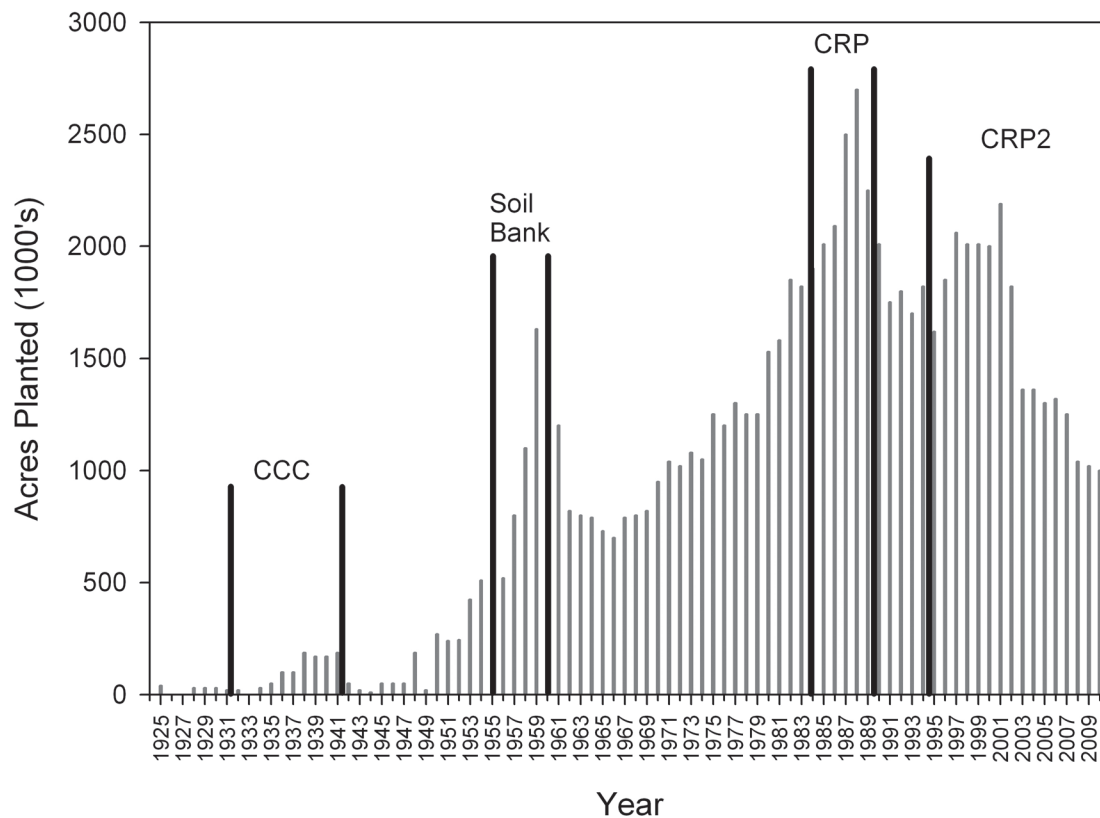
The number of state nurseries in the south also fluctuated with these trends and peaks, responding to the needs of each of these programs. From 1920 to 2011, state nurseries peaked in their numbers in 1956 and have seen a steady decline to their current total of 16, presently (Table 1). Although improvements in seedling culturing technology have increased the efficiency of seedling production, and hence the need for less nurseries, other factors, such as larger industry nurseries coming online, have contributed to the decreased numbers.

The following article briefly summarizes the federal programs that contributed to tree planting trends in the south since 1925. The overlay of state nursery numbers is also presented.

## Civilian Conservation Corps

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Tree planting in the South began before 1932 but these early efforts were generally localized and of a limited in scale. The first period of tree planting in the South was the CCC tree planting program which ran from 1932 until 1941. The tree planting efforts of the CCC marked the first time that a region-wide, large-scale tree planting project was attempted by the federal government. This program was suspended as the tree planters who worked with the CCC tree were absorbed into the war efforts that began in December of 1941 after the bombing of Pearl Harbor. During the CCC period, 17 state nurseries were in operation and almost 202,000 ha (500,000 ac) were planted.



**Figure 1.** State nurseries and total tree planting in the south: 1925 to 2010. Four distinct peaks in the number of acres planted correspond to the Civilian Conservation Corps (CCC), the Soil Bank program, the Conservation Reserve Program (CRP), and the expanded Conservation Reserve Program (CRP2).

## Soil Bank Program

The CRP was initiated by the USDA as a part of the Soil Bank Act of 1956. This has become known as the Soil Bank program and ran from 1956 to 1960. The purpose of the Soil Bank program was to encourage landowners to retire cropland and to install conservation practices; tree

planting was one of the accepted conservation practices. During the Soil Bank program, 46 state nurseries were operating in the South. At the beginning of this period just over 202,000 ha (500,000 ac) of trees were being planted per year; at its peak (1959 & 1960), 3 times as many acres were being planted. Attributing to this boost in numbers were significant advances in cultural practices (Abbott and Eliason 1968).

**Table 1.** State operated forest nurseries in the southeastern United States 1920 to 2011.

<p><b>Alabama</b> John R. Miller Nursery Jake Stauffer Nursery Edward A. Hauss Nursery</p>	<p><b>Kentucky</b> Pennyrile Nursery Louisville Nursery <b>John P. Rhody Nursery*</b> <b>Morgan County Nursery*</b></p>	<p><b>Oklahoma</b> Stillwater Nursery <b>Forest Regeneration Center*</b> Broken Bow Nursery</p>	<p><b>Virginia</b> Charlottesville Peary New Kent Forestry Center <b>Augusta Forestry Center*</b> <b>Garland Gray Forestry Center*</b></p>
<p><b>Arkansas</b> Bluff City Nursery <b>Bacum Nursery*</b></p>	<p><b>Louisiana</b> Alexander State Forest Nursery Oberlin Nursery Northwest Nursery <b>Columbia Nursery*</b> <b>Beauregard Nursery*</b> <b>Monroe Nursery*</b></p>	<p><b>South Carolina</b> Camden Nursery Georgetown Nursery Sumpter Nursery Tilghman Nursery Old Piedmont Nursery Coastal Nursery <b>Taylor Nursery*</b> Rock Hill Nursery</p>	<p>* Nurseries still in operation</p>
<p><b>Florida</b> Prison Farm Nursery Munson Nursery Harry Baker Nursery <b>M D Andrews Nursery*</b> Herren Nursery</p>	<p><b>Mississippi</b> Mt. Olive Nursery Winona Nursery Waynesboro Nursery</p>	<p><b>Tennessee</b> Pinson Nursery <b>East Tennessee Nursery*</b></p>	
<p><b>Georgia</b> Herty Nursery Davisboro Nursery Flowery Branch Hightower Nursery Horseshoe Bend Page-Walker Nursery Morgan Nursery <b>Flint River Nursery*</b></p>	<p><b>North Carolina</b> Griffith Nursery J.S. Holmes Nursery <b>Goldsboro Nursery*</b> Ralph Edwards Nursery <b>Linville River Nursery*</b></p>	<p><b>Texas</b> Conroe Nursery Kirbyville Nursery Indian Mound Magnolia Springs <b>West Texas Nursery*</b></p>	



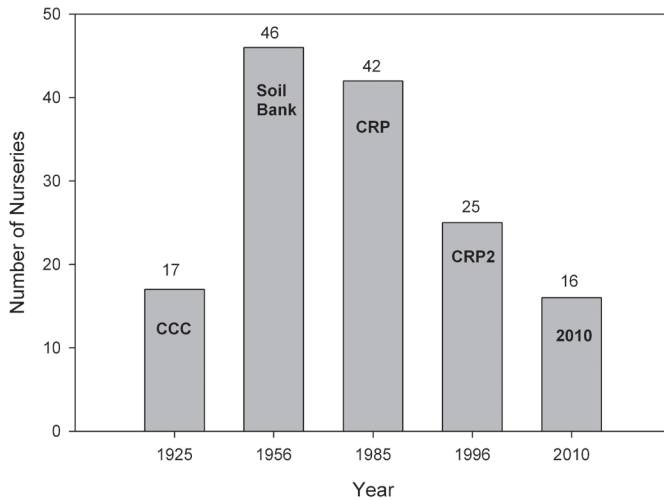
## Conservation Reserve Program \_\_\_\_\_

The 1986 CRP was designed to convert highly erodible cropland to less intensive uses. Tree planting was included in the acceptable practices of the 1986 CRP. From 1986 to 1990, the area of trees planted per year ranged from an estimated 688,000 to 1.1 million ha (1.7 to 2.7 million ac) in the South. The success of this program can be best illustrated by the 2.3 billion seedlings that were planted nationwide (South 2005).

## Expanded Conservation Reserve Program \_\_\_\_\_

From 1996 to 2011, the Conservation Reserve Program expanded (CRP2) for agricultural producers and landowners to better conserve and improve their natural resources, especially with longleaf pine (Enebak 2011). This enhanced program increased the tree planting opportunities for landowners and briefly created a spike in acres planted from 1996 to 2001. While the total number of state nurseries decreased from 42 to 25 (Figure 2), the expanded program still averaged an estimated 1.6 million acres of trees per year (Figure 1).

The creation and expansion of these programs had a profound effect on state nurseries. An examination of seedling production shows this effect. In 1939, the 17 state nurseries that were operating produced 77,205,000 seedlings, but by 2010, the 16 state nurseries still in operation produced 118,299,000 seedlings. This dramatic increase was the result of increased mechanization, improved seed quality, and an improved understanding of seedling growth and development. These improvements made it possible for production to reach 2.3 billion tree seedlings in one year at the peak of the CRP. At the same time, the numbers of state nurseries were also at their all-time high of 42. Correspondingly, as the CRP slowed down, the number of state nurseries also decreased.



**Figure 2.** State operated forest nurseries in the southeastern United States: 1920 to 2010.

## Conservation Reserve Program and Hardwood Seedling Production \_\_\_\_\_

The CRPs not only encouraged the planting of conifers but also stimulated the planting of hardwoods. In 1965, state nurseries produced more than 9.8 million hardwood seedlings, forest industry nurseries produced 1.7 million seedlings, and federal nurseries 368,000 seedlings (a total of more than 11.8 million seedlings)(Rowan 1972). Since then, the number of hardwood seedlings produced has increased to 29.2 million (in 2009), with state nurseries still producing 44% of the total and private and industry nurseries producing the majority (46 and 11%, respectively)(Enebak 2011). The production of hardwood seedlings has been a positive one in the last 20 years. Because hardwood seedlings have a higher unit sales price, the increase in production has added extra revenue to forest seedling nurseries.

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# Reforestation of Unused Surface Mined Lands by Replanting with Native Trees

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**Abstract:** More than 600,000 ha (1.5 million ac) of mostly forested land in the Appalachian region were surface mined for coal under the Surface Mining Control and Reclamation Act. Today, these lands are largely unmanaged and covered with persistent herbaceous species, such as fescue (*Festuca* spp.) and sericea lespedeza (*Lespedeza cuneata* [Dum. Cours.] G. Don.), and a mix of invasive and native woody species with little commercial or ecological value. Some landowners and surrounding residents would like to restore native forests on some of these lands for the valuable products and services they provided prior to mining. Research and experience shows that native tree species can be reestablished on these lands through replanting with seedlings, but interventions are needed if those planted trees are to survive and thrive. For these lands to become productive forests, it is necessary to loosen compacted mine soils, correct chemical or nutrient deficiencies, and control the current vegetation as cultural practices to aid survival and growth of planted seedlings. Reforestation guidelines to restore native forests on mined lands that are unoccupied, unmanaged, and unproductive were developed. Practices include land clearing, mine soil tillage, fertilization, tree planting, weed control, and monitoring. Under leadership provided by the Appalachian Regional Reforestation Initiative, a group formed by the Office of Surface Mining and seven state regulatory authorities, these procedures have been adopted and applied by watershed improvement groups, forestry and fish/wildlife agencies, coal companies, environmental groups, and an electrical generating company pursuing carbon credits.

**Keywords:** Appalachian coal fields, ecosystem restoration, mine reforestation, ARRI, tree planting, Office of Surface Mining

## Introduction

More than 600,000 ha (1.5 million ac) of mostly forested land in the Appalachian region were surface mined for coal under the Surface Mining Control and Reclamation Act (SMCRA, Public Law 95-87). Most of this land was reclaimed using practices intended to stabilize the surface, prevent erosion, and establish vegetation suitable for domestic livestock or wildlife. Today, these lands are largely unmanaged and covered with persistent herbaceous species, such as fescue (*Festuca* spp.) and sericea lespedeza (*Lespedeza cuneata* [Dum. Cours.] G. Don.), and a mix of invasive and native woody species with little commercial or ecological value. Some landowners and adjacent publics would like to restore native forests on some of these lands for the valuable products and services they provided prior to mining. Re-establishing productive forests on otherwise unused and non-productive mined lands will generate economic value for landowners and communities. This will also enhance environmental quality by accelerating restoration of ecosystem services – such as watershed protection, water quality enhancement, carbon storage and wildlife habitat – that are typically provided by native forests on non-mined landscapes.

Today, lands being actively mined in several Appalachian states are often reclaimed using the Forestry Reclamation Approach (FRA) (Burger and Torbert 1992; Burger and others 2005), which establishes productive forest as a post-mining land use in accord with SMCRA. In 2004, the Office of Surface Mining, United States Department of Interior (OSM) and the seven state regulatory authorities in Appalachia created the Appalachian Regional Reforestation Initiative (ARRI) to advocate and promote the use of this FRA to reestablish healthy, productive forest habitat

in the eastern coal fields (Angel and others 2005; Burger and others 2005). The reforestation guidelines in this publication are intended for lands mined and reclaimed without the FRA that are not forested and not under active management. They are intended for application on *unused* mined land, including those lands mined since 1980, reclaimed to satisfy SMCRA guidelines, bond released, and now under landowner control. Land mined before 1980, some of which has been identified as “abandoned mined land” could also be reforested using these guidelines. For these lands to become productive forests, intervention is needed to loosen compacted mine soils, correct chemical or nutrient deficiencies, and replace the current vegetation.

This purpose of this paper is to 1) describe a set of practices that can be applied to restore native forests on *unused* mined lands that are unoccupied, unmanaged, and unproductive; and 2) show the extent to which these reforestation guidelines have been adopted and applied on mined sites by ARRI foresters and various partnering organizations and landowners.

## Reforestation Guidelines for Unused Mined Land

Forest restoration on unused mined lands typically requires a sequence of steps or procedures over several years. In a Virginia Tech Cooperative Extension Bulletin, Burger and Zipper (2011) describe the process within the context of “four Ps” - “Plan, Prepare, Plant, and Protect” as follows:

- 1) Assess site conditions and develop a forest restoration *Plan*;
- 2) *Prepare* the site to make it more favorable for forest establishment;
- 3) *Plant* a combination of valuable, native trees or plantation species;
- 4) *Protect* the site and new planting with follow-up management, including weed control, fire prevention, and animal and human trespass.

Each of these steps are described below.

### Develop a Reforestation Plan

Step one entails assessing site conditions and writing a reforestation plan. Based on this assessment and written plan, contractors or other entities can be sought for completing the needed reforestation operations. In consultation with the landowner, the plan should include a detailed map of the site, a vegetation survey, a test and evaluation of mine soil physical and chemical properties, the forest type and species to plant, weed control methods to be used, and procedures for monitoring post planting conditions and success.

A GIS map or an aerial or satellite photo is useful to determine area and to record the assessment survey, as well as a record of all reforestation procedures applied. Aerial imagery that is freely available on internet mapping sites can be used to prepare a base map and to estimate areas. Herbaceous plants and woody shrubs, many of them non-native and invasive, often dominate reclaimed post-SMCRA mine sites (Zipper and others 2007). Successful reforestation requires that existing vegetation be eliminated or controlled. Thus, the reforestation plan must include a strategy to control competing vegetation. The site should be surveyed in advance of reforestation to determine where deep tillage is needed and how it will be applied. Deep tillage of dense mine soils produces a favorable soil condition where roots can extend easily and access needed water, nutrients, and air. Sampling mine soils and sending the samples to a state or private testing lab for chemical analyses can provide information on soil chemical properties to determine if correc-

tive measures are needed. The site map can show where specific tree species mixes will be planted. Tree species selection should be based on landowner objectives and the capability of the site. In most cases, mined land is suitable for mixed native hardwoods.

### Prepare the Mined Site for Planting

Preparing the mined site for planting usually requires three steps: 1) removing and controlling existing undesirable vegetation; 2) improving the mine soil’s chemical properties by adding lime and fertilizer; and 3) improving the mine soil’s physical properties by deep tilling with a dozer to alleviate mine soil compaction and consolidation.

It is essential that the pre-existing vegetation be controlled because it will otherwise compete for sunlight, water, and nutrients needed by tree seedlings to survive and grow. Because the pre-existing vegetation has well-established rooting and physical stature, it has an advantage over newly planted seedlings. If pre-existing vegetation is not controlled, it will quickly overtop and out-compete planted tree seedlings, and those seedlings will not survive. Woody stems that will interfere with reforestation operations should be killed and removed prior to soil preparation. Herbicides should be applied to control herbaceous vegetation both before and after planting tree seedlings.

Soil fertility is essential to the planted trees’ growth, and soil pH affects plant availability of soil P. In the short term, access to essential nutrients enables quick, early growth of planted seedlings; this is desirable because post-planting herbicide applications can cease once the planted seedlings overtop their competition. Over the longer term, adequate fertility is essential to forest productivity. Apply lime and fertilizer if necessary to improve the mine soil’s fertility and chemical properties. Lime is usually easy to apply with standard, commonly available equipment. However, fertilizers must be applied strategically to restrict availability to the planted trees only and prevent stimulation of competition by undesirable vegetation.

When mine soils have become compacted, soil loosening is needed to allow normal rooting, water infiltration, drainage, and movement of air into the soil profile, all of which are required for productive tree growth. A recent study showed significant increases in survival and growth of native hardwood species when planted in ripped or loose-dumped soil (Michels and others 2007). Compacted mine soils can be loosened with a soil ripper, sub-soiler, or other specialized tillage device. Because forest trees require at least 1.2 m (4 ft) of rooting depth for adequate growth, ripping compacted mined sites to at least 1 m (39 in) is recommended. This deep tillage operation typically requires a large dozer (Figure 1), but the equipment should be transportable via public roads. Application of deep tillage to active mines is described by Forest Reclamation Advisory No. 4 (Sweigard and others 2007); these practices can be adapted for use on older mined sites.



**Figure 1.** Single shank ripping with a D9 dozer on an abandoned surface mine site near White Oak, Tennessee.

## Plant the Site with Selected Tree Species

Over many decades, native hardwoods are likely to re-establish on unused Appalachian mined lands through natural processes, but these processes are hindered by the vigorous, non-forest vegetation that occurs on most mine sites. Natural invasion by heavy-seeded tree species – including oaks (*Quercus* spp.) and hickories (*Carya* spp.) – occur even more slowly, especially on larger mine sites, because these species' seeds are not carried by wind or birds. Plant tree species suited to reforestation goals. If the goal is to reestablish the native forest, plant a mix of native hardwoods. These trees should be commercially viable hardwoods that will provide multiple benefits including wood products, carbon sequestration, wildlife habitat, and watershed control.

## Protect and Survey the Site and Trees

Young, planted trees are vulnerable to a variety of hazards, especially through their first year. Competing vegetation prevents seedlings from accessing the sunlight, water, and nutrients they need to survive. Perhaps not so obvious, rodents such as voles, will use a heavy sod cover for winter shelter and de-bark the tree seedlings for a winter food source, thereby killing the trees. Control of competing vegetation with herbicides is essential to reforestation success on virtually all reforested mine sites.

Stocking surveys are needed to determine success of the reforestation effort. To foresters, the term “stocking” means the number of living trees per unit area at a given point in time, and is usually expressed as trees/hectare. A planting rate for mixed hardwoods on mine soils is commonly 1700 trees/ha (680 trees/ac). Expected average survival in the region is 80% at the end of the first growing season and should level off at 70% by the end of the second growing season when trees should be fully recovered from transplanting shock and growing freely without excessive competition. At this stage, minimum stocking should be approximately 1200 trees/ha (480 trees/ac). If stocking is inadequate after the first growing season from poor survival due to droughty summer conditions or other factors, additional planting can be done the following winter.

In September of the planted trees' first year, assess tree survival and stocking by determining the number of trees/ha still living. Mid-summer of the trees' first growing season is their most critical period; trees that survive the mid-summer heat and drought will generally make it through the fall and winter and into the next growing season. Assess site stocking (trees/ha) after the mid-summer heat has passed but while the trees still have their leaves, so living trees are easy to identify.

When the guidelines described above are applied appropriately, productive Appalachian forests can be restored on unused mined lands. Detail on how to apply these guidelines is provided in Virginia Tech Cooperative Extension Bulletin 460-144 (Burger and Zipper 2011).

## Application and Adoption of Reforestation Guidelines for Unused Mined Land

In 2004, OSM and the seven state regulatory authorities in Appalachia created ARRI to reestablish healthy, productive forest habitat on active and abandoned mine lands in the eastern coal fields (Angel and others 2005). ARRI's goals are to plant more high-value hardwood trees on surface mines, increase the survival rates and growth rates of those trees, and expedite the establishment of forest habitat through natural succession. The ARRI Core Team was created to facilitate and coordinate among the coal industry; landowners; university researchers; the watershed, environmental and conservation groups; and State

and Federal government agencies that have an interest in creating productive forestland on reclaimed mined lands. The ARRI Science Team was established to ensure that the methods ARRI promotes are based on proven science and research, and to guarantee the continued scientific research into forestry reclamation. See the following website for more information about the reforestation initiative in Appalachia: <http://arri.osmre.gov/>

To promote proper mine land reforestation on active mine sites, ARRI advocates using a set of best management practices called the Forestry Reclamation Approach (FRA). The FRA is a 5 step process that includes: 1) Create a suitable rooting medium for good tree growth that is no less than 1.2 m (4 ft) deep and comprised of topsoil, weathered sandstone, and/or the best available material; 2) Loosely grade the topsoil or topsoil substitutes established in step one to create a non-compacted soil growth medium; 3) Use minimally competitive ground covers that are compatible with growing trees; 4) Plant two types of trees – early successional species for wildlife and soil stability and commercially valuable crop trees; and, 5) Use proper tree planting techniques.

Focused efforts by ARRI are beginning to change the way surface mines are being reclaimed by the coal industry and regulatory authorities currently operating in Appalachia. Since the start of ARRI in 2004, approximately 70 million trees have been planted and approximately 41,683 ha (103,000 ac) restored to forests on newly mined land. ARRI is ‘forward looking,’ diligently working to educate and train the active mining industry and regulatory personnel about the FRA in order to reclaim new surface mine disturbances to forests from this point forward.

ARRI is also ‘looking backward’ at the estimated 300,000 ha (741,000 ac) of non-forested, unused, post-bond release mined lands that could be available for reforestation in the Eastern US. The reforestation guidelines for unused mined land (Burger and Zipper 2011) have been applied by ARRI to selected mined sites for restoring unused mined land to native forests. In 2009, 2010, and 2011, ARRI partnered with state and federal agencies, watershed groups, coal operators, conservation groups, environmental organizations, faith-based groups, and numerous universities, colleges, and high schools to coordinate 45 volunteer tree planting projects/events throughout Appalachia. These events involved 241 ARRI partner organizations (Table 1) and 4,163 ARRI volunteers and resulted in the planting of approximately 644,000 trees on about 372 ha (919 ac) of previously reclaimed mine sites where reforestation was not attempted, or where the results were undesirable. ARRI's role in these endeavors is to facilitate communication, provide technical assistance, and to match funding sources with suitable mined land and volunteer groups. ARRI foresters coordinated site selection and evaluation, herbicide treatments, ripping activities, species selection, tree planting, and follow-up surveys.

This post-reclamation reforestation effort has the additional benefit of outreach and awareness that is being created for proper mine land reforestation with the public, industry, and regulatory authorities. Ripping and tree planting partnerships with several mining companies on some of their previously reclaimed mine lands have led them to embrace the FRA on their active mining operations. Many state and federal regulators involved in the volunteer tree-planting projects have expressed positive attitudes for the forestry post-mining land use and employing the FRA on the ‘front-end’ of the reclamation process instead of as an ‘after the fact’ process.

On all ARRI planting sites, disease-resistant American chestnut (*Castanea dentata* [Marsh.] Borkh.) trees are planted along with all the other hardwood seedlings. Most of the chestnuts planted are classified as 15/16 backcrosses. The backcrosses are 15/16 American for form and functionality, and 1/16 Chinese for blight resistance. All chestnuts are protected with tree tubes, stakes, and weed mats.

Locations are established using GPS. Scientists with The American Chestnut Foundation and several ARRI Science Team researchers will continue monitoring these plantings.

ARRI foresters return to each planting site after planting to measure survival, productivity, and natural regeneration, and to see what can be learned from the projects to improve the success of future projects. Initial observations show that ripping a site (Figure 2) prepares a seedbed for natural succession. Succession on most sites had been heretofore arrested or substantially slowed because of the mine soil compaction and aggressive herbaceous competition. An immediate response in plant community succession on ripped tree planting sites has been observed. Early successional species such as red maple (*Acer rubrum* L.), sycamore (*Platanus occidentalis* L.), cottonwood (*Populus deltoides* Bartram ex Marsh.), dogwood (*Cornus florida* L.), black locust (*Robinia pseudoacacia* L.), big tooth aspen (*Populus grandidentata* Michx.) are frequently observed volunteers. ARRI foresters have also noted vigorous colonization of non-woody plants and native and non-native forbs such as, horseweed (*Conyza canadensis* [L.] Cronquist), ragweed (*Ambrosia artemisiifolia* L.), aster (*Aster* L.), goldenrod (*Solidago canadensis* L.), lambsquarter (*Chenopodium album* L.), wild carrot (*Daucus carota* L.), and coltsfoot (*Tussilago farfara* L.). The biodiversity on the planting sites increases rapidly; instead of 2-3 dominant non-native grasses and legumes, there is an invasion of myriad native plant species due to the site preparation conducted for each project. For planted trees, there was 83% survival for the first year on sites planted in 2009 and 2010. Second-year survival on sites planted in 2009 remained at 83%. Although initial survival is very promising, reforestation success on these sites is a function of the trees' ability to grow freely above the competing vegetation, avoid hazards including animal browse and rodent damage, and tolerate adverse mine soil conditions that could not be ameliorated. After only three years of experimentation, it is too early to determine the overall success of these forest establishment efforts. ARRI foresters continue to monitor these sites in an attempt to test and refine the reforestation methodologies established by Virginia Tech for previously reclaimed sites (Burger and Zipper 2011).

## Long-Term Outlook

After three years of piecing together tree planting projects with donated trees, in-kind services, volunteer tree planters, and very limited funding, the ARRI tree planting events are now evolving into large-scale projects funded by grants, cost share programs, utility companies seeking carbon credits, and corporate donations. Most of this funding is used for site preparation and purchasing seedlings. In



**Figure 2.** A single shank ripper pulled by a D11 was used on this gently sloping area to a depth of  $\approx 2$  m on the University of Kentucky's Bent Mountain Reforestation Research Complex in Pike County, Kentucky. Surface water retained in the rips reduces runoff, erosion, and sedimentation.

many situations, volunteer tree planters will still be needed. In response to the growing interest in planting trees on old mine sites, the ARRI Science Team created a non-profit organization called Green Forests Work (GFW). The GFW program is an economic development plan for Appalachia styled after the Civilian Conservation Corps of the 1930s. The GFW program will focus on restoring ecosystem services on mine-scarred lands and creating jobs in the process. Successful reestablishment of the hardwood forests that once dominated these lands will provide a renewable, sustainable multi-use resource that will create economic opportunities while enhancing the local and global environment. The jobs would include everything from nursery jobs, equipment operators, tree planters, forest managers, and wildlife biologists to those that may manage these sites for renewable energy and climate change mitigation.

Forests are a renewable resource. By recreating forests where no forests currently exist, the economic opportunities provided by this program will not only provide for the Appalachian people today but will put those lands on a trajectory that will ensure that a forest is available for use by future Appalachian citizens. The Appalachian forest is one of the most beautiful in the world, is one of the region's most valuable assets, and has played an integral part in the rich cultural heritage of the mountain people. As support for the program grows, GFW can proceed in developing a skilled green workforce to restore, protect, and manage this natural resource that is so vital to the region's current and future prosperity. For more information on GFW see [www.greenforestswork.org](http://www.greenforestswork.org).

## Conclusions

There is an opportunity to reforest thousands of acres of unused mined land in the Appalachian region to restore the products and services the original forests provided prior to removal by surface mining. Most of these unused land areas are covered with non-native and exotic vegetation that provide few products and services to landowners and surrounding communities. ARRI is actively working with various landowners, conservation groups, and financial sponsors to restore native forests. Reforestation of these sites is challenging due to the nature and condition of these mined lands. Burger and Zipper (2011) developed specific procedures that are being applied by ARRI and its cooperators on various sites throughout the Appalachian coalfields. The first attempts to restore native forests on unused mined sites appears to be successful, but they showed that aggressive control of competing vegetation and strategic application of nutrients to stimulate height growth by planted trees while minimizing stimulation of competition are important components of the unused mined lands' reforestation strategy.

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**Table 1.** ARRI Partners on Tree Planting Projects on Post-Bond Released Mine Lands in Appalachia in 2009, 2010, and 2011.

Alabama Division of Forestry	DriWater, Inc	McFall Excavating	Sizemore, Judy (Writer and Arts Consultant)
Allegany Coal and Land Company	Duke Energy	Meadow Mountain Boys Camp	Starbucks
Allegany County Career and Technical Center	Eastern Coal Regional Roundtable	Michigan State University	Stone Forestry Services, Inc
Alpha Natural Resources	Eastern Kentucky Environmental Research Institute	Miller, Mary (Sierra Club)	SUNY at Geneseo, NY
American Forest Heritage	Eastern Kentucky University	Missouri State University	Tampa Electric Company
American Municipal Power	Eastern Kentucky University Arts & Humanities Collab	Morehead State University	Tennessee Mining Association
AmeriCorp National Civilian Community Corp	Flatwoods Job Corps	Mountain Association for Community Economic Dev.	Tennessee Valley Unitarian Universalist Church
Anderson County LEARN Center	Flying Roster Farm	Mountain Ridge High School	Terra Tech Engineering of Grundy, VA
Appalachia – Science in the Public Interest	Food City of Wise, VA	Mountaintop Mining	Texas A&M University
Appalachian Coal Country Watershed Team	Foundation for Pennsylvania Watersheds	Mullens, Alcieberry (landowner)	The American Chestnut Foundation
Appalachian Regional Reforestation Initiative	Friends of Cheat River	Mullens Ministerial Association	The Baum Foundation
Appalachian School of Law	Friends of Coal, Ladies Auxiliary	National Park Service	The Forest Management Company
Appalachian State University	Friends of the Russell Fork	Natural Resources Conservation Service	The JOBS Project
Appalshop	Frostburg Pizza Hut	Natural Res Conser Serv, Appalachia Plant Mat Cntr	The Nature Conservancy
Arbor Day Foundation	Frostburg State University	Norfolk Southern Foundation	Union Concrete, Division of RBS Inc
ArborGen	Garrett County Watershed Association	Northern Kentucky University	Unitarian Church of Knoxville
Arizona State University	GenOn Energy, Inc	Northern West Virginia Brownfields Assistance Center	Unitarian Universalist Fellowship of Cumberland
Armstrong Conservation District	Geo/Environmental Associates, Inc.	Notre Dame University	United Nations Environmental Programme
Army Corps of Engineers	Georgetown University	Oakbrook Church, Reston, VA	United States Army Corp of Engineers
Barnesville Area Reforestation Kommittee	Girl Scouts of America	Office of Surface Mining, USDI	United States Fish and Wildlife Service
Bates, Dr. Artie Ann (landowner)	Glade Creek Elementary	Ohio Department of Natural Res, Div of Res Mgmt	United States Forest Service, Daniel Boone Natl Forest
Bates, William Van (landowner)	Glade Middle School	Ohio State University	United States Forest Service, Monongalia Natl Forest
Beaver Local High School Environmental Club	Green Forest Works	Oxford Mining	United States Forest Service, Northern Research Station
Berea College	Green Peace	Paramont Coal Company Virginia, LLC	Union Concrete, Division of RBS Inc
Bereans for Appalachia	Groundwork Wyoming County	Patriot Coal Company	University of Kansas
Birch River Elementary	Guest River Restoration Project	Penn's Corner RC&D Council	University of Kentucky
Blue Mountain Area High School	Headwaters, Inc	Pennsylvania Dept of Consv & Nat Res, BAMR	University of Notre Dame
Boy Scouts of America, Grantsville, MD	Highlandtown Wildlife Area	Pennsylvania Dept of Consv & Nat Res, BOF	University of the Cumberland
Boy Scouts of America, Hazard, KY	Hill Creek Nursery	Pennsylvania Dept of Consv & Nat Res, Sproul Forest	University of Vermont
Boy Scouts of America, Port Carbon, PA	Huntington Bank	Pennsylvania Dept of Environmental Protection	Upper Guyandotte Watershed Association
Bryant, Lee (landowner)	Hutchinson, Chad (AFLAC agent)	Pennsylvania Game Commission	Upper Tennessee River Rountable
Buckanan County Industrial Development Authority	Indiana University of Pennsylvania	Pennsylvania State University, Schuylkill	Vaughan Bassett Furniture Company
Buffalo Middle School	Interfaith Youth Core	Perry County Future Farmers of America	Virginia Cooperative Extension
Burch Middle School	International Coal Croup Eastern, LLC	Personal Responsibility in A Desirable Environment	Virginia Department of Mines Minerals and Energy
Cabot Oil and Gas Corporation	James River Coal Company	Pine Branch Coal Company	Virginia Division of Forestry
Camp Dawson National Guard	Jeffco Resources, Inc	Pine Grove Area High School	Virginia Mining Association
Camp Robert C Webb	Jenkins High School	Pine Mountain Grill	Virginia Tech
Campus Christian Center	JTW Gas Well Service	Pine Mountain Settlement School	Wal-Mart (Frostburg, MD)
Carter Caterpillar	JW Adams Elementary	Plum Creek Timberlands, LP	Wal-Mart (Minersville, PA)
Central Appalachian Spruce Restoration Initiative	Ken and Coy	Premier Elkhorn Coal Company	Wal-Mart (Schuylkill, PA)
Central Michigan University	Kent State University	Reading Anthracite	Webster County High School
City College of New York	Kentucky Department of Fish and Wild- life Resources	Richwood High School	Wes-Mon-Ty Resource Conservation & Development
Clairfield Elementary School	Kentucky Division of Abandoned Mine Lands	River City Drum Corp	Western Kentucky University
Claude Worthington Benedum Foundation	Kentucky Division of Conservation	Roaring Run Watershed Association	Western Maryland RC&D Council
Cliffs Natural Resources, Inc.	Kentucky Division of Forestry	RPM Ecosystems LLC	West Virginia Department of Environmental Protection
Clintwood Elementary	Kentucky Division of Mining Reclamation Enforcement	Ruffed Grouse Society	West Virginia Department of Natural Resources
Clintwood Elkhorn Coal Company	Kentucky Riverkeepers	Rural Appalachian Improvement League	West Virginia Division of Forestry
Coal Creek Watershed Foundation	Kiski Realty Company, Inc	RW Combs Elementary	West Virginia National Guard, Camp Dawson
Coal Heritage Highway Authority	Kopper Glo Fuel, Inc.	Saddleback College	West Virginia University
Coldwell Timber Consulting	Kopper Glo Fuel, Inc.	Samara of Berea College	Wheelock College
Columbiana County Federation of Conservation Clubs	Letcher County Central High School	Sara Lee, Inc	White Oak Elementary School
Columbiana County Park District	Let's Move Outdoors	Savage River Watershed Association	Williams Forestry & Associates
Columbiana Soil and Water Conservation District	Lexington Christian Academy Beta Club	Saylor, Doug (Consulting Forester)	Woman's Club of Morgan County, KY
Conservation Services, Inc	Little Beaver Creek Land Foundation	Scenic Rivers Program	Woodland Community Land Trust
Cowan Creek Mountain Music School	Lonesome Pine Soil and Water Conservation District	Schuylkill Conservation District	Wyoming County Board of Education
Crystal, Denny and Merrill (landowners)	Longs Fork Elementary	Schuylkill County Commissioners	York, Larry (landowner)
Cub Scouts of America, Grantsville, MD	Lowe's Home Improvement – Beckley, WV	Schuylkill Headwaters Association	Young Men's Club of America
Delaware Valley Earthforce	Loyola University	Shavers Fork Coalition	Young Professionals of Eastern Kentucky, Inc.
Dickenson County School System	Marquis Development of Williamson, WV	Shelby Valley High School	
Dominion	Maryland Dept of the Environmt, Water Mgmt Adm	Shell Heirs (landowners)	
Drew University	Maryland Forest Service	Sierra Club – Bluegrass Chapter	
	Maxxim Shared Services		
	McClure River Restoration Project		

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# Evaluating Reforestation Success on a Surface Mine in Eastern Kentucky

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**Abstract:** Reclamation through reforestation is becoming more common in Kentucky as studies uncover what treatments are most effective for successful tree establishment. “Success” is defined by the Commonwealth of Kentucky in terms of height and survival percentage of outplanted and naturally regenerated species. While this definition of success provides a measure of site occupancy, it does not produce an adequate method for characterizing the quality of the reforested mine land as compared to the natural landscape. In response to this, a method of site evaluation was developed for two high-value hardwoods, white oak (*Quercus alba* L.) and yellow-poplar (*Liriodendron tulipifera* L.). Tree growth data were gathered from 80 even-aged, naturally regenerated reference stands located in the eastern Kentucky coal fields. For each species, eight stands for each of five age classes were sampled (5, 10, 20, 40, and 80). Tree height and diameter measurements taken from reforestation plots planted on reclaimed mined land in eastern Kentucky were compared to the reference sites. Loose-dumped and, in some instances, strike-off reclamation produced tree growth that was somewhat similar to what was found in the natural stands of eastern Kentucky, whereas conventional reclamation techniques largely inhibited tree growth. Yellow-poplar and white oaks grown on mine soils were shorter but larger in diameter than what was found in the reference stands. Mulch was a necessary component for the establishment and growth of both species on mined land.

**Keywords:** site quality, white oak, yellow-poplar, reforestation, reclamation

## Introduction

Reforestation of surface-mined lands is becoming more common in the eastern United States as studies uncover what reclamation techniques are effective for successful tree establishment and growth (Angel and others 2009). “Success” is currently defined in terms of the height and survival of outplanted and naturally regenerated species. The Commonwealth of Kentucky mandates that to achieve final bond release, the mining company must show that every tree counted has at least one-third of its height in live crown and that at least 80% of the counted trees used to determine success have been in place for 3 years or more (Commonwealth of Kentucky 1993). Although these criteria provide some information on reforestation status, they fail to grasp the overall quality of the trees or site. Further, current methods of height assessment are based on the use of regional site indices that were developed from the analysis of 50-year-old trees. Even though site indices have been shown to be very useful on maturing stands, these indices are not suitable for evaluation of 5-year-old seedlings.

The site index (SI) has had widespread use throughout Appalachia to determine timber volume and site quality (Stout and Schumway 1982; Lamson 1987). The benefits of using SI to evaluate a forest stand include good correlation with site productivity, easy measurement, and independence from stand density (McQuilkin 1989). In order for SI to be accurate and meaningful, the site must have suitable trees within the required height and age range, and there needs to be accurate SI curves available by which to measure the site (Sims 1994). Suitable trees are those that have been free to grow into a dominant or codominant crown position, have a straight single stem, have been free from suppression, and have not been significantly damaged (McQuilkin 1989).



Despite the advantages and widespread use of SI, it has limitations, especially when considering overall stand development. Site index curves cannot be applied to stands without suitable trees or for the conversion of species (Pritchett and Fischer 1987). When measurements are taken in stands that represent a suite of age classes, problems arise because 5- to 40-year-old stands may not be comparable to indices generated from measurements taken from older trees. In this case, it is recommended to sample multiple stands and develop new curves fitted to the existing data (Carnean 1975). Spurr and Barnes (1973) found that curves constructed in this manner did not accurately represent actual stand growth curves, and that SI ranges need to be equally represented at all ages, which may not be feasible due to harvesting or other land practices. Harrington and Loveall (2006) reported problems using SI in southwestern US ponderosa pine (*Pinus ponderosa* [Dougl. ex Laws.]) stands due to the high index age and the extended time it took for the stand to attain adequate size for measurement. Site index also assumes that the growth rate is proportional at all ages and for all qualities of sites, which is not the case (Beck and Trousdell 1973). Finally, even though the SI is a good estimator of a single variable, volume, it provides scarce information towards understanding the biology and development of a site (Pritchett and Fischer 1987).

The aforementioned methods of site quality evaluation are traditional and based on minimally disturbed land; however, methods are needed that compare stands on highly disturbed sites with a reference, or natural, stand of trees to determine site quality and reforestation success. The concept of a reference system approach for site quality is a relatively new one. Moore and others (1999) gave three definitions of the concept: 1) a standard used to measure the variability of natural conditions in an ecosystem (Kaufmann 1994; Swanson and others 1994; Kaufmann and others 1998); 2) a standard used to measure change in an ecosystem (Morgan and others 1994; Kaufmann and others 1998); and 3) a standard used to measure the success of ecological restoration or management objectives (Christensen 1996). This system of site quality evaluation has been used to measure restoration success of watersheds (Hessburg and others 1999), tallgrass prairie (Brye and others 2002), giant sequoia (*Sequoiadendron giganteum* [Lindl.] Buchholz) (Stephenson 1999), and ponderosa pine (Moore and others 1999). Even though ecologists use the term "reference system" to mean a pristine system not tampered with by humans, it may also represent the ultimate goal, regardless of disturbance, of any restored ecosystem.

Carnean (1975) reported the need to develop integrated methods of site quality evaluation and landscape classification that include information about mensuration, soils, and ecology; he further stressed the need for information about both yield quality and quantity. Based on previous methods of site-quality evaluation, a method specific to the Appalachian coal fields needs to be developed that characterizes the vast diversity and abundance of these forestlands. Although this method will not restore forests to their former ecological status, it will help provide a greater understanding on whether current reforestation methods are working effectively.

The forests of central Appalachia are diminishing at a high rate due to surface mining. For many reasons, these forests are essential to the identity, productivity, and stability of the region's ecology and economy. There is a need for a method that can be used to evaluate survival on mined lands and concurrently determine if the stand is on a similar growth trajectory as that found in a naturally regenerated forest on non-mined land. Quality is desired by landowners as much as, if not more than, quantity. Properly managed forests provide the landowner with a long-term investment not only in the form of income from wood and fiber production, but also through water supply and filtration, land stabilization, wildlife habitat, ecosystem biodiversity,

air filtration, carbon sequestration, and numerous other non-wood forest products (Zipper and others 2011). Burger (1999) stressed that reforestation success must not be a matter of numbers and percentage of survivability; rather, emphasis must be placed on developing stands that produce the products listed above at optimum levels. It was recognized that the current methods of reforestation assessment were inadequate and served few purposes other than achieving bond release for the mining company.

Given that efforts to re-establish stands disturbed by surface mining have not been completely effective, a study was designed to develop growth curves based on observations of tree height, diameter, and age that accurately characterize even-aged, naturally regenerated white oak (*Quercus alba* L.) and yellow-poplar (*Liriodendron tulipifera* L.) forests found in eastern Kentucky. This reference data was then used to assess outplanted tree growth on reforested mine lands in eastern Kentucky.

## Materials and Methods

### Species Selection

Two hardwood species were chosen for this project, white oak and yellow-poplar. Both species are native to the region, highly valued for a variety of reasons, and key components of the native ecosystem (Beck 1990; Rogers 1990). Further, there is an abundance of each species in the region that provided ample opportunities for finding suitable study areas.

### Study Area Description

The majority of the study area was located in the Eastern Coal Fields physiographic region of Kentucky, with a small number of sites falling into the Eastern Pennyroyal region. This section of the Cumberland Plateau has been thoroughly described in two parts, the Northern Cumberland Plateau (Smalley 1986) and the Cumberland Mountains (Smalley 1984) that border the southern edge of this section of the plateau. A historical description of the region is found in Braun (1950).

### Reference Study Sites and Measurements

Within 20 counties in the study area, 80 reference study sites (40 for each species) were identified, established, and measured. The 40 study sites per species were further subdivided into five age classes (5, 10, 20, 40, and 80 years old); each age class was composed of eight study sites. These criteria were established to show a chronosequence of development that could be used to describe the reference range for various silvicultural variables. Most of the study sites were located on public land, namely the Daniel Boone National Forest (DBNF), Kentucky Nature Preserves, Kentucky State Parks, and the University of Kentucky's Robinson Forest. A majority of the 5-year-old sites were found on private land.

Requirements for site selection included: even-aged; ample sampling points ( $n=30$ ); favorable slope position and aspect for the species measured; relatively free of pest and disease damage; within the correct age range; and similar land use history as the majority of the other sites. Age ranges for the various stand classes were organized as depicted in Table 1.

Once a suitable area was identified, a 10-m (33-ft) buffer was paced off from any road or other edge and the start point was randomly established and flagged as 0. Using an engineering tape, a 20-m (66-ft) transect was laid out parallel to the contour of the slope, and flags were placed at 10-m (33-ft) and 20-m (66-ft) points. From the 0-, 10-, and 20-m flagged points, perpendicular transects were established to a length of 20-m, making a 400-m<sup>2</sup> (4300-ft<sup>2</sup>) site. On these per-

**Table 1.** Age class determination for even-aged cuts.

Age Class	Age Range	Years Cut
5	4 to 6	1999 to 2001
10	8 to 12	1993 to 1997
20	17 to 23	1982 to 1988
40	36 to 44	1961 to 1969
80	75 to 85	1920 to 1930

pendicular transects, the 10-m and 20-m distances were flagged and designated as six replicated plot centers within the site.

The 5 closest dominant or codominant trees to each plot center were measured as sample trees. Each site had 30 sampling trees for a total of 2,400 sampling trees measured. On older stands exhibiting low tree density, the overall sampling area was increased to obtain the necessary 30 sample trees. Sampled trees had to be healthy, dominant or codominant canopy trees, single stemmed, unsuppressed, relatively undamaged, and not significantly bigger or smaller than the age class being sampled (McQuilkin 1989).

Thirty trees on each site were measured for total height using a Haglof Vertex Laser Hypsometer (Haglöf Sweden AB, Långsele, Sweden). Diameter-at-breast height (DBH) was determined with a standard dbh tape. Due to their short height, all 5-year-old seedlings were measured 2.5 cm (1 in) above mineral soil for a ground line diameter. Two trees per study site were cored and the cores were sanded and analyzed in the lab for stand age. Due to small girth, trees in the 5- and 10-year-old study sites were lopped and a section was cut, sanded, and evaluated for stand age.

Other information recorded for each study site included slope, aspect, elevation, GPS location, directions, and plot layout. For each species, total vegetation observations per age class were summed and plotted to show diversity trends in yellow-poplar and white oak plots between 0 to 80 years of growth.

## Mine Site and Measurements

The Starfire Mine is located in Perry and Knott Counties, Kentucky. It is a mountain top removal mine that has been in operation since the early 1980s. In 1996 and 1997, the University of Kentucky established nine 1-ha (2.5-ac) reforestation test cells (Thomas and others 1999). These cells were constructed to represent three subsurface treatments: conventional (3 cells); strike-off (3 cells); and loose-dump reclamation (3 cells). Conventional reclamation that results in a highly graded, smooth, and compact surface is the accepted practice of surface mining. Strike-off reclamation is a method in which the spoil is loosely dumped in piles, and then the tops of the piles are "struck off" with the use of a bulldozer, resulting in a moderately compact surface. Loose-dumped reclamation occurs when the spoil is loosely dumped in piles and left alone, and creates the least compact planting material. Micro-topography of the three subsurface treatments varied greatly, ranging from completely smooth ground (conventional) to extremely rough (loose-dumped) (Angel and others 2006). Surface amendments (straw-manure compost) were also applied to portions of each cell at a rate of 125 tons/ha (50 tons/ac), and other areas were left alone to serve as the control.

Each cell was divided into twenty-one 0.04 ha (0.1 ac) growth plots into which a particular species was planted. Six bare-root (1+0) tree species, including yellow-poplar and white oak, were planted in 1996 and 1997 (Angel and others 2006). One corner of each plot was permanently marked with rebar and metal tags identifying plot number and species planted within the plot. Each tree species was randomly allotted to three plots (three replications) within each reclamation cell. Tree seedlings were planted on 1.8- by 1.8-m (6- by 6-ft) spacing,

providing 121 trees in each growth plot. The growth plots are separated by 3-m (10-ft) wide alleyways that provide access to the plots without damaging the growing trees.

Since the inception of the Starfire Mine reforestation plots, annual measurements of height, survival, and diameter have been recorded and compiled into a database. These measurements were obtained, organized, analyzed, and used as a test for the method developed by this study. Nine years of data from Starfire were obtained, but because growth was negligible in the first 4 years, only the past 5 years of data were used for tree height and diameter comparison.

It is important to note that the reforestation plots on Starfire Mine were too young at the time of measurement to have reached canopy closure. These were planted stands at predetermined spacing that created a more open growing condition than what is typically encountered naturally; it is therefore likely that trees in these plots did not experience the same intense competition for resources as would be found in a natural stand. When stand density is not excessive, a seedling does not have to grow in height as fast to outcompete its neighbors, and it can allocate more resources to diameter growth. For example, a mature tree grown in an open field will likely be shorter than one found in a fully-stocked forested stand, given the same site quality, due to the reduced pressure on available resources.

## Statistical Analysis

For each species, tree heights and diameters were totaled and averaged per age class. The reference range for early (0 to 20 years) height growth was developed by plotting the averages and upper and lower standard deviations for height at 5, 10, and 20 years. All three lines were then linearly regressed to show the average growth trajectory and the upper and lower standard deviation trajectories around it. Linear regression was used to depict early growth because of competition pressure and self-thinning typical of young stands.

To depict the long-term (0 to 80 years) reference range for height growth, a similar method was used, with the exception of using averages from all age classes (5, 10, 20, 40, and 80), and regressing them logarithmically. Early and long-term diameter reference ranges were developed in an identical manner as was done for the height reference ranges. Independent t-tests assuming unequal variance were used to compare reference height and diameter means to mine plot height and diameter means for the past 5 years of growth on the mine (SAS Institute 1999).

## Results and Discussion

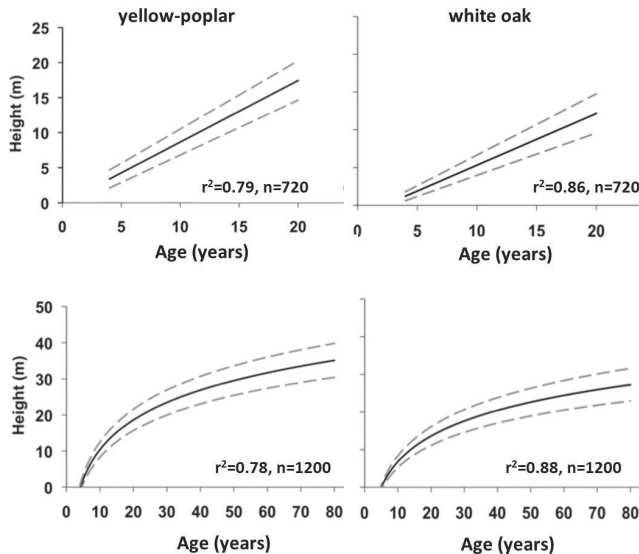
### Characterization of Reference Study Sites

Yellow-poplar and white oak were favorable species to study due to the abundance of both in eastern Kentucky forests. The defined patterns of site preference, both temporal and spatial, for both species became clear as sampling progressed. The majority (37.5%) of yellow-poplar sites had a northwest aspect, although northeast, north, and east aspects were also common (25%, 17.5%, and 10% of sites, respectively). Usable yellow-poplar sites were found on lower (42.5% of the sites), mid (40%), and upper (17.5%) slope positions. Elevation of the yellow-poplar sites averaged 374 m (1227 ft), with a low of 263 m (864 ft) and a high of 679 m (2229 ft).

For white oak sites, 40% were situated on southwest aspect, but sites were also found on southeast (25%), south (15%), west (10%), and northwest (5%) aspects. White oak sites were mainly found on upper slope positions (47.5%), with fewer sites on the lower (27.5%) and mid (25%) slope positions. Average elevation was 380 m (1247 ft) for white oak sites with the highest at 645 m (2115 ft) and the lowest at 286 m (939 ft).

## Reference Height Development

Nyland (2002) summarized the four phases of even-age stand development as: 1) stand initiation, which can last up to two decades and in which there is a rapid accumulation of living vegetation; 2) stem exclusion, characterized by high mortality caused by competition pressure and self-thinning; 3) transition, during which the permanent understory forms in gaps created over time; and 4) steady-state, in which the biomass of the stand fluctuates only slightly and remains fairly stable (after Bormann and Likens 1979; Oliver 1981; Spies 1997). Reference height ranges were depicted to reflect the above stand development phases by showing a linear trend for the 0 to 20 year old stands and a logarithmic trend for the 0 to 80 year stands (Figure 1).



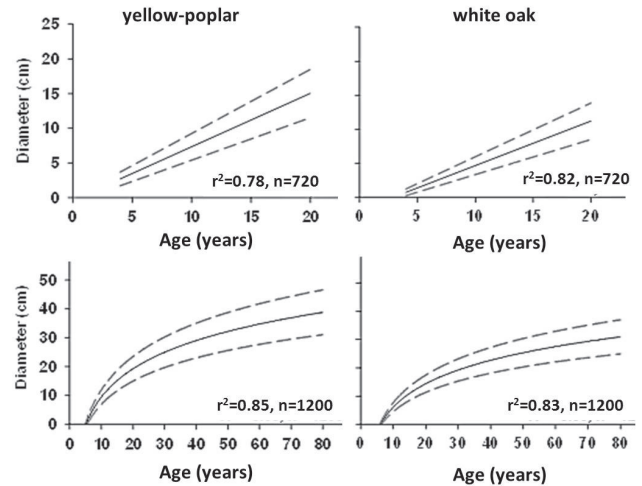
**Figure 1.** Reference height range for yellow-poplar and for white oak at 0 to 20 years and 0 to 80 years.

Measured yellow-poplar heights corresponded well to those observed by Beck (1990) in unthinned second-growth Appalachian stands. He reported mean heights at age 20 of 15.8 m (51.8 ft), at age 40 of 27.1 m (88.9 ft), and at age 80 of 35.1 m (115.2 ft). Another study from Robinson Forest, Breathitt County, Kentucky, by Eigel (1978) reported mean heights of yellow-poplar on side slopes at age 41.8 to be 29.1 m (95.5 ft) on YP SI (102). The mean SI at age 50 for all yellow-poplar stands in this study, calculated through regression, was 29.5 m (96.8 ft). An SI of 80 at age 50, indicating an average site quality, was obtained for the 80-year-old yellow-poplar stands in this study using the Southern Appalachian Mountains curves (Beck 1992).

Information on white oak heights at specific ages was not as readily available. Rogers (1990) reported that on the poorest sites, the SI for white oak exceeded that of yellow-poplar; on better sites where white oak co-dominated with yellow-poplar and other oaks, however, the SI for white oak was generally less than that of yellow-poplar. Honeycutt (1981) examined white oak growth in Robinson Forest and found, at a mean age of 57 on Shelocta soils on mid slope position, a mean height of 21.0 m (68.9 ft). The mean height of 40-year-old stands in this study was 20.1 m (65.9 ft), indicating that the site quality for this age class, when compared to the sample from Honeycutt's study, was likely higher. The mean SI at age 50 for all white oak stands in this study was 22.6 m (74.3 ft). When the 80-year-old mean height was used to calculate SI based on the upland oak SI (Carmean and others 1989), an index of 75 was obtained, which indicates high-quality site for white oak.

## Reference Diameter Development

For reasons explained earlier, diameter curves were plotted linearly for 0 to 20 years and logarithmically for all age classes sampled (Figure 2). Height was easily comparable among stands due to its relative independence from the effects of density; diameter, however, was not as comparable since it was directly affected by stand density (Schifley 2004).



**Figure 2.** Reference diameter range for yellow-poplar and for white oak at 0 to 20 years and 0 to 80 years.

Yellow-poplar diameter measurements from this study were similar to those reported in the literature. Beck and Della-Bianca (1970) examined naturally regenerated yellow-poplar stands in the southern Appalachians and found a mean diameter at age 20 of 20.8 cm (8.2 in); this was higher than our study mean. Another study by Beck (1989) reported the mean diameter for yellow-poplar stands at age 40 to be 28.5 cm (11.2 in) on YP SI (120) that was almost identical to the corresponding mean in our study. The same study revealed that at age 80 on YP SI (100) the mean diameter was 44.7 cm (17.6 in), slightly higher than the study mean. Eigel (1978) reported a mean diameter of 29.0 cm (11.4 in) at age 39 for six yellow-poplar trees measured in Robinson Forest.

Honeycutt (1981) studied white oak in relation to topography and soil in Robinson Forest and found a mean diameter of 23.0 cm (9.1 in) at age 40; this was slightly higher than the average for this study. Crown position has been cited as the single most important factor in tree diameter growth (Trimble 1969). An oak that has a superior canopy position will gain diameter faster than an overtopped oak. While collecting data, an attempt was made to sample trees that were as similar as possible, and crown position was always considered. Regardless, the standard deviations for diameters for both species in age classes 20, 40, and 80 were consistently higher than standard deviations for height, indicating that variation in diameter was influenced by changes in stand density during the stem exclusion phase (Schifley 2004).

## Tree Height in Reference and Reclamation Sites

The primary objective of this study was to discern the quality of degraded lands in eastern Kentucky; there are no lands in this state that have been disturbed more than those affected by surface mining. The Starfire Mine presented a good opportunity to test the method against trees growing on reforestation plots outplanted on land reclaimed by three different methods with or without straw-compost amendment: conventional; strike-off; and loose-dumped reclamation.

**Table 1.** Yellow-poplar and white oak survival percentages for Starfire Mine reforestation cells, 1997 to 2005. Treatments, by species, for 2005 followed by the same letter are not significantly different ( $\alpha \geq 0.05$ ).

Species	Method	1997	1998	1999	2000	2001	2002	2003	2004	2005
Yellow-poplar	Loose-Dump	93	86	77	64	83	82	79	80	77 a
	Strike-off	94	63	61	51	59	57	54	52	52 b
	Conventional	59	50	30	9	15	15	9	11	10 c
White Oak	Loose-Dump	88	69	87	70	83	80	84	81	80 A
	Strike-off	94	55	78	66	68	71	70	69	69 B
	Conventional	49	25	49	25	27	27	24	21	25 C

Tree survival has consistently been over 50% in the loose-dumped and strike-off cells since 1997 (Table 2). These numbers may be satisfactory with respect to obtaining bond release for the mining company, but they tell us nothing about the quality of these sites, nor do they provide us with any information about the suitability of the site for long-term forest development. With this in mind, height growth (Figure 3) and diameter growth (Figure 4) were analyzed and compared to growth trajectories from the reference sites.

Caution must be exercised in interpreting the height growth trajectory for yellow-poplar in the conventional reclamation because the straw-amended plot was unusually high (Figure 3). Although the heights of the yellow-poplars in these plots were comparatively tall, there was very low

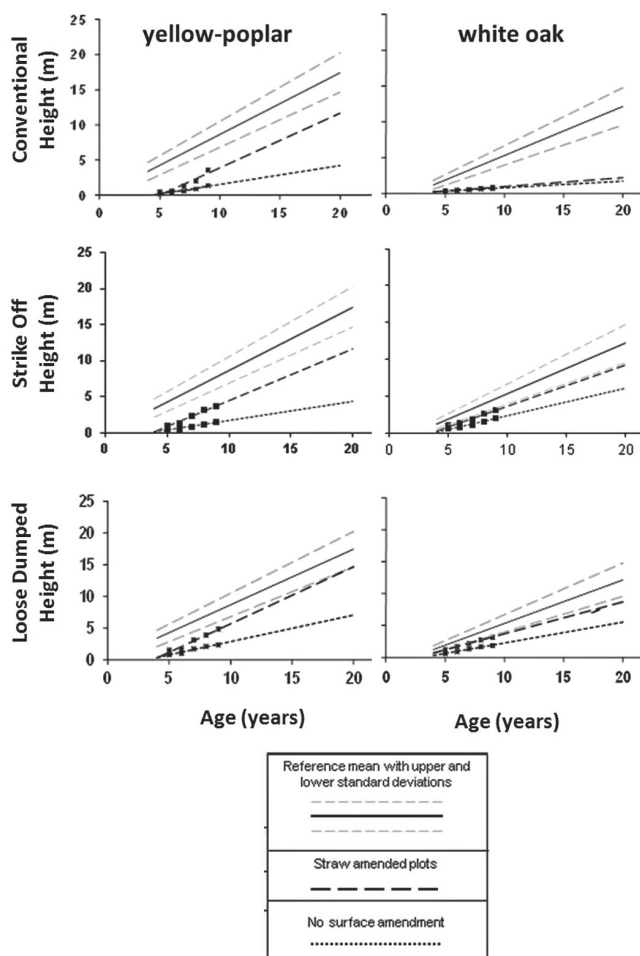
survival (<3%) for the conventional plots in 2005. The height growth trajectory for white oak seen in Figure 3 more accurately reflected the conditions that trees typically faced on conventionally reclaimed mine land—both growth trajectories for the straw-amended and control plots were almost flat and well below that of the reference. The high degree of compaction hindered root development, hydraulic conductivity, and nutrient uptake, and thereby caused the trees to grow at a stunted pace (Conrad and others 2008). Surface water on these plots either ponded or ran off at a rapid pace due to the compaction. Anoxic conditions were an additional problem facing tree development in these areas.

Tree heights in the strike-off and loose-dumped plots came closer to reference range (Figure 3), and reflected the looser spoil material that allowed better rooting capacity, water retention, and nutrient flow. White oak heights were closer to reference range than yellow-poplar in the strike-off plots, possibly because they were more drought tolerant. Strike-off reclamation produced slightly more compact spoil that may have resulted in higher runoff amounts and drier conditions.

Loose-dumped reclamation (Figure 3) resulted in tree heights in both species that most closely approached the tree heights found in the reference stands. If conditions remain the same in the yellow-poplar plots, these heights may reach reference heights just before they reach age 20. Thomas and others (1999) reported using yellow-poplar in reclamation plots on Starfire Mine because it was native, fast growing, had a rapidly growing market, and had a documented performance in land reclamation. Early research on sites mined before the Surface Mining Control and Reclamation Act of 1977 (pre SMCRA) in southern Illinois (Ashby 1978) showed that uncompacted sites resulted in some of the most productive areas in the state for growth of yellow-poplar and white oak. Another study found that five of six hardwood species (including white oak and yellow-poplar) showed increased survivability as compaction was minimized on Starfire Mine (Angel and others 2006). White oak seedling establishment is best on loose soil because the radicle cannot penetrate excessively compacted surfaces (Rogers 1990).

Statistical analyses indicated that the average heights on all surface and subsurface treatment plots for the most recent year collected (growing year 9 or 2005) were significantly less ( $P < 0.001$ ) than the reference mean of the same age. This was not surprising, even on loose-dumped spoil, due to the open growing conditions the out-planted trees experienced on the mine.

It must be emphasized that a surface amendment must be used when tree planting on mine-reclamation sites to achieve acceptable performance after outplanting. The straw-amended plots outperformed the control plots for all three reclamation methods (Figure 3). The use of mulch is a common practice in reclamation due to its ability to control erosion, supply nutrients, protect seedlings, alleviate compaction, reduce evaporation, and stabilize soil temperatures (Angel and others 2006; Evangelou 1981; Plass 1978). Francis (1979) reported that on frangipan soils, yellow-poplars grown on bedded plots were taller than those planted without bedding. Another study revealed that bedding reduced soil bulk density values for loblolly pine stands and



**Figure 3.** Chronosequence of height development for yellow-poplar and white oak comparing reference stands to reforestation plots on Starfire Mine, with and without straw mulch amendment, and reclaimed with conventional reclamation, strike-off reclamation, and loose-dumped reclamation.

increased total porosity and macroporosity by 19% and 24%, respectively (Lister and others 2004). While these benefits are important, the addition of nutrients through mulch cannot be understated, as mine spoils are often deficient in nutrients. Early investigations of spoil material found that these soils were deficient in nitrogen (Schramm 1966); however, later studies reported that nutrient availability in spoils was as variable as the spoil itself (Lindsay and Nawrot 1981). Rodrigue (2001) concluded that the nutrition of a spoil was dependent on the surface overburden material, its pH, and its degree of weathering, and that the variability of the nutrient content was reflective of variable site conditions after mining.

### Tree Diameter in Reference and Reclamation Sites

Diameter growth was also examined in the same manner as height, using the reference range graphs (Figure 2) as a base against which we compared diameter development of outplanted trees on Starfire Mine (Figure 4). Compared to height growth, diameter growth of trees on the reforestation plots was similar to the reference stands in some instances. Often, tree plantings on mines are measured only for height and survival because these attributes are key to bond release, and there exists sparse information about comparable diameter measurements.

As with height, the results for yellow-poplar in the conventional reclamation plots reflected an inflated straw-amended growth trajectory

due to the low survival of yellow-poplar trees from those cells in that year (Figure 4); white oak diameters, however, showed little response to growing on conventionally-reclaimed mine land (Figure 4). The compacted spoil in these cells inhibited diameter growth primarily by restricting water and nutrient flow to the tree. When tested, mean diameters for both species produced from conventionally reclaimed mine land, with or without mulch, were significantly different and lower than those found in the reference stands.

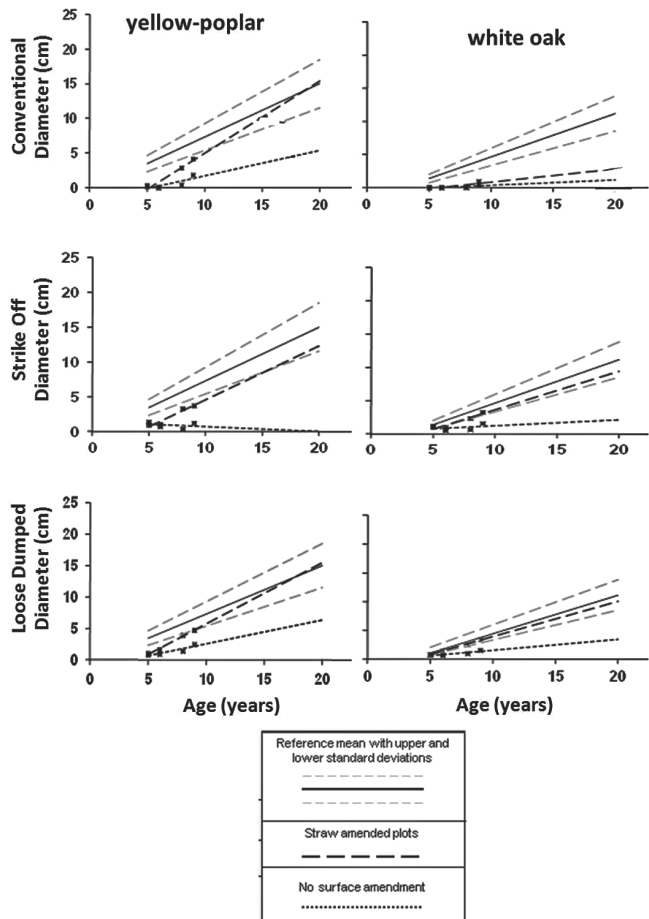
Diameter growth was dramatically improved on strike-off reclamation for both yellow-poplar and white oak when amended with straw mulch (Figure 4). When mean diameters at age 9 were compared between reference stands and mine plots, there was no significant difference between the two ( $P = 0.06$ ) for white oak, indicating that, with respect to diameter, this surface and subsurface combination (strike-off and straw mulch) achieved conditions similar to reference stands for white oak growth. Although it appeared that yellow-poplar diameter growth was very close to reference, the means were significantly smaller ( $P < 0.001$ ).

A similar trend occurred in the loose-dumped plots. White oak diameters from the mine plots at age 9 were actually significantly larger than those in the reference sites ( $P = 0.0026$ ) (Figure 4), which suggested that the open-grown conditions and surface and subsurface treatments resulted in white oaks allocating more carbon to diameter than to height growth. On the other hand, yellow-poplar mean diameters were significantly smaller than those found in the reference stands, but are expected to be similar within the next 2 years.

From the analysis of height and diameter growth found on the mine plots, we are growing shorter trees with larger diameters compared to those found in reference stands in the eastern Kentucky coalfields. We believe this is occurring for a couple of reasons. First, the growing medium on the mine plots did not, for the most part, have the same nutrient or water availability as what was found in the reference stands. Second, the open growing conditions and predetermined spacing of the outplanted trees on the mine plots created less competition pressure that likely allowed the trees to allocate more resources to diameter growth versus height growth.

### Conclusions

There is a need to qualitatively evaluate reforestation projects on mined land in eastern Kentucky to ensure future economic and ecologic benefits, goods, and services that healthy forests provide. Conventionally reclaimed land often holds little promise in the way of future forest development. Tree heights and diameters from conventional stands were consistently lower than those found in undisturbed reference stands. On the other hand, loose-dump and strike-off reclamation had positive effects on yellow-poplar and white oak development. Additionally, the use of mulch proved to be essential for producing height and diameter growth similar to that found in reference stands through its ability to mitigate compaction and nutrient availability. Mulch likely served to jump-start the establishment of a microbial population that was necessary to cycle essential nutrients on a newly formed, unweathered soil. Mulch may also have alleviated compaction through reducing bulk density and increasing total porosity. Finally, mulch seemed to enhance the initial nutrient availability of the spoil where there was none before and allowed seedlings an early source of nutrients. The hardwood reference system of evaluation described in this paper appears to be a good means to assess stand quality on disturbed sites. Its value is two-fold in that one may evaluate the surrounding natural forests as well as the disturbed land. In this way, it may provide an additional tool to evaluate and predict stand quality and future development of the unique forests found in eastern Kentucky.



**Figure 4.** Chronosequence of diameter development for yellow-poplar and white oak comparing reference stands to reforestation plots on Starfire Mine, with and without straw mulch amendment, and reclaimed with conventional reclamation, strike-off reclamation, and loose-dumped reclamation.

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# Restoring the American Chestnut Tree

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Burhans B, Hebard FV. 2012. Restoring the American chestnut tree. In: Haase DL, Pinto JR, Riley LE, technical coordinators. National Proceedings: Forest and Conservation Nursery Associations—2011. Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. Proceedings RMRS-P-68. 24-25. Available at: [http://www.fs.fed.us/rm/pubs/rmrs\\_p068.html](http://www.fs.fed.us/rm/pubs/rmrs_p068.html)

**Abstract:** The American chestnut (*Castanea dentata*) was a dominate hardwood tree in the eastern United States. Its historic range extended from Maine south to the northern parts of Georgia, Alabama, Mississippi, and west to the Ohio River Valley. In 1904, an exotic Asian fungus responsible for the death of American chestnut trees was first identified at the Bronx Zoo (New York City, NY). By 1950, the fungus (*Cryphonectria parasitica*) had spread throughout the range of the chestnut and had functionally removed the chestnut as a canopy tree. The American Chestnut Foundation (TACF) was established in 1983 with the mission of restoring the species to our eastern woodlands to benefit our environment, wildlife, and society. TACF currently operates over 300 breeding orchards representing over 120,000 chestnut trees throughout the range of the species. TACF has begun outplanting and testing their first line of potentially blight-resistant chestnuts. In addition, TACF is developing trees resistant to ink disease, and is using biotechnology to develop blight-resistant chestnut trees and to increase efficiency of its breeding program.

**Keywords:** American chestnut, *Cryphonectria parasitica*, ink disease, backcross breeding, The American Chestnut Foundation, chestnut blight

## Introduction

The American chestnut (*Castanea dentata*) was once the “King of the Forest,” the single most prevalent hardwood tree in the eastern half of the United States. At one time, nearly one out of every four canopy trees was an American chestnut. Some of those trees were giants, reaching heights in excess of 30 m (98 ft) and diameters (at breast height) in excess of 3 m (10 ft). They often were branch-free for the first 15 m (49 ft).

The natural range of the American chestnut extended from Maine south to the northern parts of Georgia, Alabama, and Mississippi, and west to the greater Ohio River Valley and the western end of Lake Erie.

During the first half of the 20th century, an Asian fungus (*Cryphonectria parasitica*) causing a disease known as “chestnut blight” was accidentally imported into the United States. Chestnut blight was first observed on American chestnut trees in the Bronx Zoo (New York City, NY) in 1904. The fungus spread quickly and more than four billion trees were destroyed across nearly 81 million ha (200 million ac) of forestland. Most of the trees succumbed to the blight. Chestnuts that didn’t initially die were often cut down to preserve the timber for future use.

In less than 50 years, the American chestnut was gone from the American landscape as a forest-canopy tree. Chestnut blight is recognized as one of the worst ecological disasters of the 20th century. Although American chestnut trees are still common in our forests today, they exist as small saplings growing from the root system of parent trees originally infected by the blight during the early 20th century; the saplings are continually knocked back by repeated attacks of the disease and rarely reach the canopy.

The American chestnut historically was an important tree for both wildlife and society. The chestnut was a staple in many American households prior to the chestnut blight. Families depended on the nuts as a major food source as well as a cash crop. Millions of bushels of the sweet-tasting nuts were hauled to cities like New York and Philadelphia and sold during the Christmas holidays. Many railroad cars were filled to the brim each year for shipment to urban areas. Farm families in the Appalachian Mountains fattened their hogs and other livestock on the nuts, and children would fill their pockets with chestnuts to snack on at school.

The most important hard mast for wildlife almost assuredly was produced by the American chestnut. Hard mast commonly available to wildlife includes acorns, hickory nuts, beech nuts, and walnuts. Mast provides wildlife with critical nutrients during the fall and winter months when other foods are scarce in the forest. The plentiful, reliable nut crop of chestnuts likely provided more nourishment than any other hard mast.



Many species likely benefited from chestnuts, including white-tailed deer, bear, raccoon, wild boar, squirrels, mice, wood rats, wild turkey, grouse, crows, and blue jays.

The American chestnut crop provided an important alternative food source when mast failure occurred in other nut-producing tree species. Because chestnut trees rely on pollination by both wind and animals, and because they flower in late spring to early summer, chestnut trees can recover from flower (and mast) failures caused by late spring frosts, unlike hickory (*Carya* spp.), oak (*Quercus* spp.), beech (*Fagus* spp.), and walnut (*Juglans* spp.).

## Restoring the American Chestnut

The American Chestnut Foundation (TACF) was established in 1983 with one clear mission: to restore the American chestnut to our eastern woodlands to benefit the environment, wildlife, and society.

Since 1983, TACF has been working to restore the American chestnut tree by breeding blight-resistant trees using a backcross tree breeding method developed by Burnham and others (1986) that involves crossing American chestnut and Chinese chestnut (*C. mollissima*). The goal of the backcross breeding program is to develop a population of trees with the growth characteristics of the American chestnut while maintaining the genes from the Chinese chestnut parents that confer resistance to chestnut blight. Burnham and others (1986) predicted that chestnuts should have adequate blight resistance by the third generation of the third backcross (B3F3).

TACF intends to continue breeding beyond the B3F3 level, but considers trees at the B3F3 level of breeding as suitable for the start of a long-term process of testing and reintroduction. As TACF develops more advanced lines of potentially blight-resistant trees, the organization will switch to using these trees for testing and reforestation efforts.

The breeding program of TACF selects for trees that exhibit both American chestnut growth characteristics and enough blight resistance to allow the tree to reproduce sexually; this is a basic requirement for the success of the breeding program. In addition, the program incorporates local germplasm through our state chapter breeding programs as well as blight resistance from multiple types of Asian chestnuts.

Developing a blight-resistant chestnut tree is an obvious and obligatory requirement of TACF's program. TACF, however, is not necessarily developing an "end product" (blight-resistant tree), but rather a population of trees with the necessary set of genes to allow the species to resume evolving through natural selection. This is a critical distinction for TACF. The organization is not developing a "crop" plant, but rather a genetically diverse wild tree species with sufficient blight resistance and American chestnut growth characteristics to be reintroduced successfully into our eastern forests.

To maximize genetic diversity within our chestnut trees, TACF established a network of state chapters throughout the historic range of the American chestnut. The chapters breed American chestnuts indigenous to their states to develop blight-resistant trees that are adapted to the environment peculiar to the state and to increase the overall genetic diversity of trees in the program. The state chapter system has developed more than 300 breeding orchards representing more than 70,000 chestnut trees.

During spring 2009, TACF partnered with the USDA Forest Service (USFS), the USFS Southern Research Station, and the University of Tennessee to initiate testing of our first lines of potentially blight-resistant chestnuts (B3F3). TACF and our partners continue to install additional outplantings and monitor growth characteristics and blight resistance in these trees.

In addition to outplantings with the USFS, TACF has established a number of additional B3F3 outplantings on both private and public lands to secure data on resistance and growth of the B3F3 trees. It is still too early in the testing process to make any meaningful evaluation of our breeding program. TACF, however, does not consider the B3F3 tree as the end of our breeding efforts. On the contrary, the B3F3 represents the beginning of a continual process of additional breeding and testing, both in structured field trials and actual reintroduction efforts.

TACF's backcross breeding program extends beyond breeding blight-resistant chestnut trees. TACF is also engaged in a breeding program designed to develop trees resistant to ink disease. Ink disease is caused by the organism *Phytophthora cinnamomi* and other *Phytophthora* spp. Many chestnut outplantings have failed due to ink disease (Jeffers and others 2007), mainly in the Southeast where this organism is common. Although chemical treatment for *Phytophthora* is effective in orchard situations (Barilovits 2009), this is not a practical approach for reintroducing the American chestnut to the wild. TACF's efforts focus on selecting for chestnuts that have both resistance to blight and ink disease at Chestnut Return Farm (Seneca, SC).

The use of biotechnology is another pathway TACF is using to develop blight-resistant trees. In partnership with the State University of New York (SUNY, ESF), Pennsylvania State University, University of Georgia, North Carolina State University, and USFS, TACF collaborators are experimenting with transgenic approaches to confer resistance, along with identifying markers to allow for more precision in our traditional breeding programs. During spring 2011, TACF's New York state chapter and SUNY, ESF planted their first transgenic chestnuts for testing and evaluation.

## Conclusion

The loss of the American chestnut resulted in a tremendous blow to the eastern forests of the US. The mission of TACF is to restore the American chestnut to our eastern woodlands to benefit the environment, wildlife, and society. To achieve this monumental task, TACF and its partners have developed a structured, yet diverse program to accomplish this mission.

TACF's program of restoration will span many generations, but is now at a juncture where trees are being outplanted and closely evaluated. Breeding will continue for many more decades but the organization will expand its scope to include ecological and silvicultural aspects of the restoration program.

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# Soil Fumigation: The Critical Use Exemption, Quarantine Pre-shipment Rules, Re-registration Decision and Their Effect on the 2012 Growing Season

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**Abstract:** This article gives a brief history of the importance of methyl bromide in the production of forest tree seedlings in the southern United States and the timeline for the Montreal Protocol and Clean Air Act to phase out ozone depleting compounds. In addition, the process, steps used, and current status under the Critical Use Exemption and Quarantine Pre-shipment articles within the treaty are discussed. A summary of the re-registration decisions proposed by the Environmental Protection Agency for the re-registration of all soil fumigants under the Food Quality Protection Act for the 2012 production season is outlined as well as the current status of MBr alternatives.

**Keywords:** Methyl bromide, soil fumigation, forest nursery, disease management

## Introduction

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In the early 1980s, scientific circles reached a consensus that the concentration of the stratospheric ozone was declining and that chlorinated fluorocarbons (CFCs) were the cause. To address this issue, the Montreal Protocol was signed in 1987 to bring about the eventual phase-out of all CFCs as well as other substances that deplete the ozone layer. In 1991, methyl bromide (MBr) was added to the list of ozone-depleting compounds, and the amount of MBr produced and imported in the U.S. was reduced incrementally until it was phased out by 1 January 2005, under the Montreal Protocol and the Clean Air Act (CAA). Within these two agreements, were two allowable exemptions to the phase-out of MBr that included the Critical Use Exemption (CUE) and the Quarantine and Pre-shipment (QPS) exemption, both designed for agricultural users with no technically or economically feasible alternatives.

## Methyl Bromide

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MBr is an odorless, colorless gas that has been used as a soil fumigant in most southern forest tree nurseries to control a wide range of soil-borne pests (Carey and McNabb 1996). Over the past 50 years, MBr has proven to be a reliable pesticide that enhances seedling production and has been the industry standard for nearly all pest management programs in forest tree nurseries. The use of MBr to control nursery pests reduced the demand for more specific herbicides, fungicides, and insecticides. Prior to the MBr phase-out in 2005, 96% of southern forest tree nurseries used soil fumigation, 90% of which was MBr (Jang and others 1993). Generally, MBr was applied once every 3 to 5 years, allowing 2 to 3 years of pine production followed by 1 to 2 years of cover crop. The total amount of MBr used annually in forest-tree nurseries was 1,600,000 lbs and was approximately 0.33% (1/3 of 1%) of the MBr used for soil fumigation in the U.S. in 1990 (Anonymous 1993). The extensive use of MBr in forest tree nurseries across the southern United States was the best indication of its consistent effectiveness across a wide range of soil and environmental conditions.

## Critical Use Exemptions

CUE are described by the Environmental Protection Agency's (EPA) website under the following guidelines (EPA 2012):

The CUEs are permitted under Section 604(d) of the CAA and the Montreal Protocol. Under Decision IX/6 of the Protocol, the "use of MBr should qualify as critical use only if the nominating Party determines that:

(a) The specific use is critical because the lack of availability of MBr for that use would result in a significant market disruption; and

(b) there are no technically and economically feasible alternatives or substitutes available to the user that are acceptable from the standpoint of environmental and public health and are suitable to the crops and circumstances of the nomination."

Thus, beginning in 2004, the Environmental Protection Agency (EPA) requested applications for CUEs from consortiums or groups of growers/users that continue to need and use MBr in their production systems. A CUE application includes a number of questions on current MBr use, production data, pest issues, research and efficacy on alternatives, methods to reduce MBr emissions, etc. that can be used by EPA to determine the "critical use." These documents can be onerous; the 2010 Southern Forest Nursery Management Cooperative's CUE application was 79 pages in length. After reviewing the CUE applications, EPA develops a Methyl Bromide Usage Numerical Index (BUNI/BUNNIE) for each consortium/group. The review takes into account each request, subtracts double reporting and quarantine pre-shipment uses, and nominates an amount of MBr for that consortium to the State Department. From the various BUNI/BUNNIEs, the U.S. Government requests authorization for those critical uses from the Parties (Methyl Bromide Technical Options Committee - MeBTOC) to the Montreal Protocol. Once the Parties of the Protocol authorize 1) the request for a critical use and 2) an amount of MBr for those critical uses, EPA publishes a rule in the Federal Register allowing for the additional production of MBr for that critical use in that year. Each application for a Critical Use round takes up to 3 years and is conducted annually. As the timeline dictates, those forest tree nurseries that use CUE MBr in 2011 began the application process in 2008; accordingly, those that want to use CUE MBr in 2014, must apply in 2011.

As growers adopted different pest management systems, the number of Critical Users has decreased over time. In 2010, there were 11 pre-plant and 3 post-harvest users/growers authorized to use MBr under the CUE process as outlined under the Montreal Protocol. Within the pre-plant users, is the Forest Nursery Seedling group that includes 6 different forest nursery consortiums throughout North America approved to use MBr in their production systems. Some of the other Critical Users include commodities, orchard replant, sweet potato slips and fruit, and nut and flower nurseries. The primary objective of the Montreal Protocol and the CAA was to reduce, and eventually eliminate, the use of all ozone-depleting compounds, including MBr. Since the first CUE in 2005, the amount of MBr requested by U.S. growers, the amount authorized by the State Department, and the amount approved by the Parties has steadily declined from 20.8 million lbs in 2005 to 2.5 million lbs in 2011, representing an 88% reduction in MBr use in the United States.

## Quarantine and Pre-shipment Exemption

As part of the Montreal Protocol, the Quarantine and Pre-shipment (QPS) rule implements a permissible exemption for production and

consumption of MBr for quarantine and pre-shipment purposes. Article 2H of the Montreal Protocol, paragraph 6 states that "the calculated levels of consumption and production under this Article shall not include the amounts used by the Party for quarantine and pre-shipment applications." The QPS exemption is based on self-certification of the individual Parties and EPA agreed to the Montreal Protocol's definitions of quarantine and pre-shipment, as described in the Handbook for the International Treaties for the Protection of the Ozone Layer (EPA 2012).

With respect to MBr, QPS applications are:

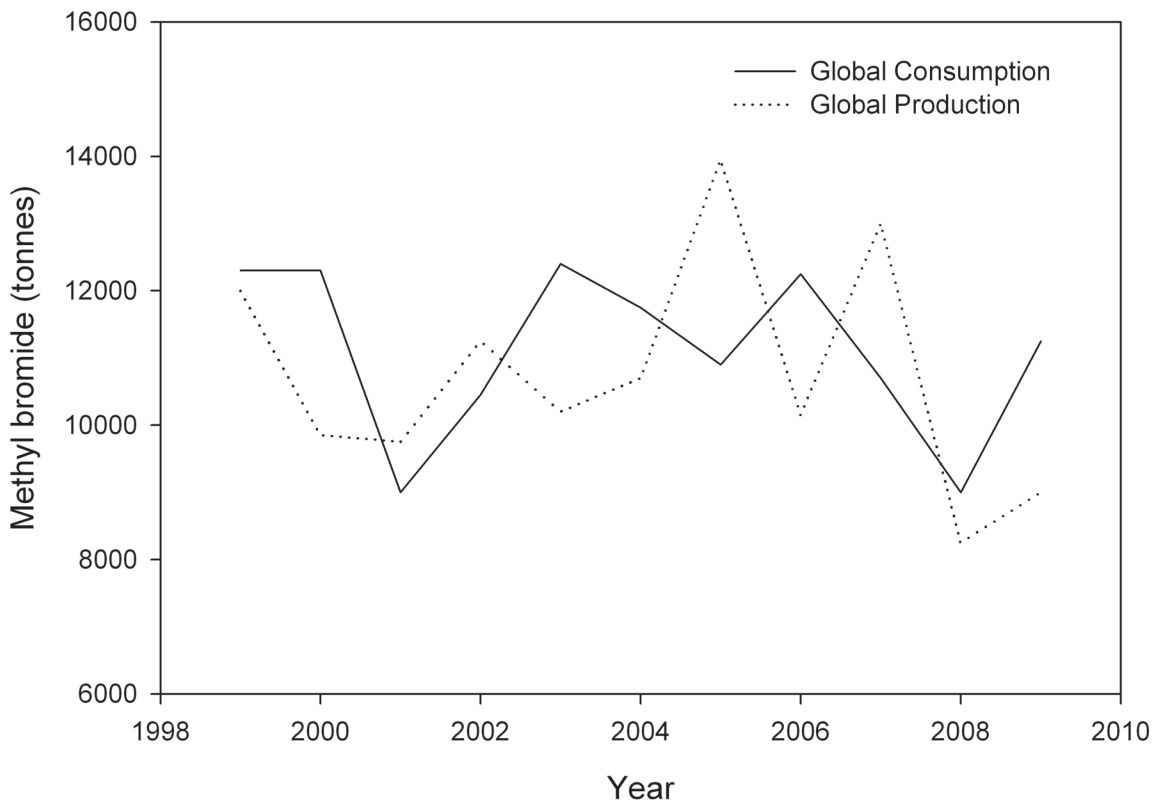
treatments to prevent the introduction, establishment, and/or spread of quarantine pests (including diseases), or to ensure their official control, where: (a) Official control is that performed by, or authorized by, a national plant, animal, or environmental protection or health authority; (b) quarantine pests are pests of potential importance to the areas endangered thereby and not yet present there, or present but not widely distributed and being officially controlled (EPA 2012).

An example of a quarantine application of MBr is the fumigation of a commodity, such as potatoes in Idaho. In this case, potatoes are subject to infestation by a specific and officially recognized quarantine pest (pale cyst nematode, *Globodera pallida*); therefore, the fumigation is conducted before commodity transport to meet official quarantine requirements.

The purpose of quarantine fumigation is to prevent the introduction of specific quarantine pest(s) into a defined geographical area, such as an importing country. 'Pre-shipment applications,' with respect to methyl bromide, are those non-quarantine applications that are within 21 days of export that need to meet the official requirements of the importing country or the existing official requirements of the exporting country. Official requirements are those which are performed by, or authorized by, a national plant, animal, environmental, health or stored product authority (EPA 2012).

As part of the CUE application and approval process, when EPA develops the BUNI/BUNNIE for each critical user, they routinely deduct a percentage of the MBr requested for each user for QPS. For example, in 2009 the Southern Forest Nursery Management Cooperative (SFNMC) requested 246,000 lbs of MBr for use in 2011 for all forest seedling producers in the southern United States. From that amount, EPA deducted 83,000 lbs for QPS uses, or 66%, and submitted 163,000 lbs to MeBTOC for CUE approval. Since the phase-out of MBr use in 2005, there has been a reported increase in the amount of MBr assigned as "QPS MBr" by the United Nations (Figure 1). Correspondingly, there has been a push by European Union (EU) nations to significantly reduce QPS use worldwide. Some claims have been made by other nations that the United States is playing games with the EU and that pre-plant uses lack efficacy data to adequately get control based on EU standards. Thus, at the International Plant Protection Convention, there were plans to rework definitions as outlined in the Montreal Protocol. At the heart of the matter, the EU claims that state boundaries, as listed and used by the United States, do not qualify for usage as QPS and that the definitions as outlined in the Montreal Protocol were for International Boundaries. Specifically, any rule put into place in the U.S. after 1993 does not count based on international rules.

In early 2010, representatives within the EPA, USDA – APHIS, and the State Department contacted the SFNMC, to clarify the role the Nursery Cooperative plays in the CUE application process as it pertains to QPS. The question posed to the Cooperative was, "If the production of forest tree seedlings falls under the QPS umbrella for



**Figure 1.** Worldwide production and consumption of methyl bromide classified as Quarantine and Pre-shipment use from 1999 to 2009 (adapted from UNEP 2010).

MBr use, why does the Nursery Cooperative even file the request for a CUE MBr use?" To that end, copies of the 12 southern State Plant Pest Requirements for Pest-Free Certification on forest tree seedling production were forwarded to those agencies for their use in negotiating CUE and QPS MBr use with the EU and MeBTOC.

The CUE and the QPS amendments were not intended to be a permanent solution for continued MBr use. While there is no "cut-off" date for either of these programs, there are still a few chlorofluorocarbons (CFCs) in use 15 years after their phase-out. The overall objective of the Montreal Protocol and the Clear Air Act was to eventually phase out and stop all uses of MBr. In July 2010, EPA announced that the agency was considering ending the CUE program by 2014, with 2013 the last year MBr would be available under the CUE process which has provided U.S. growers an additional six years beyond the 2005 phase-out of methyl bromide to implement ozone-safe alternatives. According to EPA, production and consumption of methyl bromide has "declined significantly over the last 20 years," particularly since the substance was phased out in 2005. The CUE since that time was meant to give affected industries time to develop viable alternatives to ozone-depleting substances. Developing countries have until 2015 to phase out methyl bromide. The United States was one of only five countries to request the critical use exemptions for methyl bromide in 2011. Israel has announced it will end its critical use program after 2011, while Japan has indicated it will no longer request exemptions after 2013.

In June 2011, however, EPA again requested critical users interested in requesting MBr beyond 2013 to apply for the 2014 growing season. It was at this time (June 2011) that forest nurseries discovered EPA's decision to deny their 2010 application for MBr use in 2013. Caught totally off-guard, as no notification was made to any of the 7 Forest Seedling applications, EPA's official response to their rejection of the Forest Nursery applications was:

m sodium), 1,3-D plus chloropicrin, and iodomethane plus chloropicrin. In addition, DMDS (Paladin) will be available starting in 2011 and provide an additional technically and economically feasible option. Methyl bromide will still be available as a quarantine treatment in many states.

The 2010 rejection of the CUE applications from all Forest Seedling applications by EPA means: 1) that they will not consider any new CUE applications from the Forest Nursery Sector unless it is accompanied by 5 years of research data showing that an alternative soil fumigant does not work, 2) those nurseries without any state QPS rules can use MBr in 2011 and 2012, and 3) unless a particular nursery is located in a state with appropriate QPS rules, MBr cannot be used after 2012. Furthermore, quarantine pre-shipment (QPS) use will now come under even more scrutiny than before by EPA, the State Department, and the Parties of the Montreal Protocol.

While the official EPA response has no merit research-wise, it is my opinion that the various state regulations forwarded to EPA in 2010, gave ammunition to reject the Forest Seedlings request for CUE MBr. The lack of notification (burying the rejection in the Federal Register) to those Forest Seedling applicants also raises serious questions as to the working relationship between the Office of Pesticide Programs and the Forest Nursery Industries. If EPA continues to support QPS, then the political sacrifice might be worth it; however, if EPA backs down to the European Union, then QPS use of MBr for forest seedlings is over.

## Methyl Bromide Alternatives

It is an understatement to mention that significant time, effort, and dollars have been spent within the agricultural community in an attempt

to identify an economical and technical alternative to MBr. Since 1991, when the Southern Forest Nursery Management Cooperative began to look, in earnest, for a replacement, over \$2,000,000 of its annual dues has been spent on research to find an alternative to MBr. In early 1991, the choices for an MBr replacement were chloropicrin, 1,3-dichloropropene, dazomet, and metam/potassium sodium, either alone or in combinations (Carey and McNabb 1996). Since that time, data collected from numerous trials on seedling production, pest control and application issues have narrowed that list to just chloropicrin and 1,3-dichloropropene (Telone<sup>®</sup>), alone or in combinations. Fortunately, there has been new chemistry developed and these new soil fumigants include Pic + (chloropicrin + a solvent), dimethyldisulfide + chloropicrin (DMDS = Palidin<sup>®</sup>), and methyl iodide (MI; iodomethane = Midas<sup>®</sup>). A few compounds that are currently under examination in other crop systems that use MBr, but not yet tested by the Nursery Cooperative include sulfuryl fluoride, phosphine, halosulfuron, furfural, and napropamide. However, recently another office of EPA expressed concern about fluoride getting into ground water and raised questions about fluoride sources. Consequently, all alternative soil fumigant tests in forest tree nurseries that contained fluoride (Vikane<sup>®</sup>) were discontinued by the Nursery Cooperative.

As far as a drop-in replacement for MBr, none of the soil fumigants tested by the Nursery Cooperative have performed equally in all nurseries in all situations. While producing decent seedling characteristics, Palidin<sup>®</sup> (DMDS + chloropicrin) has significant odor issues that last long into the growing season. Unless the odor is eliminated, adoption of this particular alternative is doubtful. Since its labeling in 2008, restrictions on the availability and application of Midas<sup>®</sup> (methyl iodide + chloropicrin) have limited research to 1 study in 1 nursery in 2009. Studies with other alternatives have shown that soil type, pest pressures, cropping history, and nursery location affect the efficacy of soil fumigants (Starkey and Enebak 2008; Enebak and others 2012, 2011). More studies with this compound in other nurseries and soils are needed. Data collected in 2005, prior to the Midas<sup>®</sup> label approval, resulted in iodomethane with decent seedling characteristics, but poor weed control and significant reduction of *Trichoderma* spp. (Starkey and others 2006). Despite these data, Midas<sup>®</sup> is yet to be labeled for use in either New York or Washington. Recently, (May 2011) EPA (at the request of Earthjustice) opened up a formal 30-day comment period (that was later extended due to pressure from NY Attorney General) to address the safety of iodomethane on women and children. While EPA was not legally required to do so, several other organizations are concerned about iodomethane's safety and given the pressure on EPA, it is entirely possible that the label for Midas<sup>®</sup> could be revoked. Update: In March 2012, Arysta LifeScience, the sole distributor of iodomethane in the U.S., suspended all sales of Midas<sup>®</sup> and requested that all compounds containing Midas<sup>®</sup> be returned to their distribution centers. According to a company press release, "The decision (to suspend sales) was made as part of an internal review of the fumigant and based on its economic viability in the US marketplace."

The soil fumigant Pic + (chloropicrin + a solvent) has been one of the better MBr alternatives, across a wide range of soils and nurseries where it has been tried (Starkey and Enebak 2008; Enebak and others 2012, 2011). Weed control issues have occurred in some nurseries with this compound, which is not surprising since chloropicrin is not known for its weed control (Carey and McNabb 1996; South 2006). The eventual loss of MBr is going to result in individual nurseries needing to fine-tune their seedling production and pest (weed, insect, fungi, and nematode) control treatments more carefully because the use of MBr in forest tree nurseries previously allowed for a greater degree of control due to its broad spectrum capacity.

## Reregistration Eligibility Decisions (REDs)

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Superimposed over the CUE process, the QPS rules, and the agencies that fall under the Montreal Protocol and the Clear Air Act, was the enactment of the Food Quality and Protection Act (FQPA) of 1996. With the passage of the FQPA, congress presented EPA and all producers and users of pesticides with the challenge of implementing the most comprehensive and historic overhaul of the nation's pesticide and food safety laws in decades. Some of the major requirements include stricter safety standards, especially for infants and children, and a complete reassessment of all existing pesticide tolerances for all uses and users, applicators, handlers, and bystanders.

Thus, in 2006, the EPA began the process of reviewing the safety of all compounds that are used as soil fumigants in an attempt to mitigate bystander exposure. This process took into consideration application methods, soils, compounds, rates, crops, etc. and developed rules on usage and application methods as part of the reregistration of each soil fumigant. The compounds examined in this reregistration process included chloropicrin, dazomet, metam/potassium sodium, methyl bromide, 1,3-dichloropropene (Telone<sup>®</sup>), methyl isothiocyanate (MITC), and iodomethane as a group to ensure that similar risk assessment tools and methods were used for all and that risk management approaches were consistent across all soil fumigants.

It would be an understatement to suggest that the EPA's first proposed rules in February 2007 were a major setback to over 15 years of MBr alternative research in the forest seedling arena. For example, using the newly proposed EPA rules for soil fumigants, a 10-acre block (nursery average) fumigated with 350 lbs chloropicrin under a High Density Plastic, the best alternative to MBr (see: South 2006; South and others 1997) would require a buffer zone of 1400 m (4200 ft or 3/4 of a mile). The buffer zone footprint alone represents 1874 additional acres, an unfeasible amount to control for a 10-acre block of trees. Along with the other proposed rules, the SFNMC estimated that within three years, 50% of the forest tree nurseries would have ceased operations due to a loss of production areas, with the remaining nurseries having to significantly increase seedling costs (Southern Forest Nursery Management Cooperative Internal Data: EPA-HQ-OPP-2007-0350-0226.1). It turns out that the best "alternative" to the 2007 proposed Soil REDs was the soil fumigant MBr, as it required a smaller buffer zone than straight chloropicrin. For someone who has been working on soil fumigants since 1985 (Enebak and others 1990a, 1990b, 1990c), the irony of identifying a soil fumigant as an alternative to MBr under the Montreal Protocol and work under the 2007 Soil REDs was simply a bitter pill to swallow.

Fortunately, after a number of EPA "comment periods" that included new soil flux data, information on seedling production systems, identification of high barrier tarps, evaluation of new technologies, and shareholder input, a revised and amended Soil RED was released in May 2009. These new rules will affect all aspects of soil fumigation for years to come and will require that producers, applicators and users play a role in the safe and proper application of soil fumigants for the production of forest tree seedlings. These steps include buffer zones, posting requirements, agricultural worker protection, applicator and handler training programs, tarp perforation and removal, good agricultural practices, application methods/practices and rate restrictions, new restricted use designation for dazomet, site-specific fumigation plans, emergency preparation and response requirements, compliance assistance and assurance measures, and community outreach and education programs. All of these measures are going to take a lot of time, effort, and money on someone's part to comply. Thus, the cost to use soil fumigants in the production of forest tree seedlings is going to increase more than it already has.

Prior to the implementation of the Montreal Protocol and the phase-out of MBr, the average cost to fumigate nursery soil was just over \$1500/acre. After 2005, there were two sources of MBr (CUE and

QPS) of which the cost to use was less for QPS than CUE MBr. These two sources of MBr have increased in cost since 2005 to \$3100 and \$1900 per acre in 2010, for CUE and QPS MBr, respectively. Neither producers nor applicators have any idea of what these new rules will do to the price of any of the soil fumigants (chloropicrin, MBr, Telone®) available for 2012 and beyond. Suffice to say it will cost more to fumigate soils in 2012 than it will in 2011.

While these new rules will change the way nurseries use soil fumigants, the lifting of the buffer zone overlap restrictions to 24 hr, the incorporation of the new soil flux data into the buffer tables, new plastic tarp technologies that allow the gluing of high barrier plastics (virtually or totally impermeable films – VIF or TIF), and other soil credits should allow nurseries to continue their use of soil fumigants in the production of forest tree seedlings with minimal disruptions and loss of production acreage. Without these changes, many forest-seedling nurseries would have ceased to exist, unable to comply with the bystander safety restrictions. The 10-acre field with a 4200' buffer under EPA's first rule is now reduced to 53 ft. Slated for enforcement in 2012, to date (July 2011) many of these requirements have not yet been agreed upon by the registrants and EPA. Full enforcement of all new soil rules and corresponding pesticide labels is scheduled for the 2012 growing season. That should give producers, applicators, and users a few more months to work out the kinks as EPA plans to consider the soil fumigants together (all over again) during Registration Review that begins in 2013.

## Summary

The continued availability and use of MBr for the production of forest tree seedlings is limited to those who have access to a Critical Use Exemption through 2012 or whose nurseries reside in states that fall under the Quarantine Pre-shipment rules. Both of these MBr sources (CUE and QPS) are limited and under scrutiny by a number of U.S. governmental and international organizations. A number of soil fumigants have been examined as alternatives to MBr, none as drop-in replacements as each has its own unique properties and challenges that will need to be tweaked by individual nursery managers under their own production systems. These include chloropicrin, iodomethane, di-methyl disulfide, chloropicrin & 1, 3-dichloropropene, either alone or in some combination. The new Soil Fumigation REDs that come in full force in the spring of 2012 will require a concerted effort by producers, applicators and users to ensure the safety of bystanders and document each application of soil fumigant. While the costs to fumigate will probably increase, at least the amended rules allow the continued use of soil fumigants in the unique production systems that are forest tree nurseries.

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# The History and Future of Methyl Bromide Alternatives in the Southern United States

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**Abstract:** This article gives a brief history of the efforts of the Southern Forest Nursery Management Cooperative (SFNMC) in testing methyl bromide (MBr) alternatives for soil fumigation. In the southeastern United States, fumigation with MBr has been the most commonly used method for producing high quality, pest-free forest seedlings in an environment that is conducive for soil-borne pathogens, nematodes, and weeds. As a result of the Montreal Protocol, the production and use of MBr was to be incrementally phased out beginning in 2005. Included in this process are exemptions allowing for continued use and testing of fumigants with the goal of finding an alternative that is economically feasible and efficacious. Testing by the SFNMC has shown that, although there are alternatives to MBr, they are not as efficacious. Any choice of currently available alternatives will most likely require an increase in pesticide use to compensate for alternative short-falls. The effects of all alternatives following 4 to 5 crop rotations without MBr are unknown. Currently, recommended alternatives vary in their effectiveness from one nursery to another. The most significant development in soil fumigant research in the last 5 years has been the availability of high barrier plastics that will allow lower fumigant rates to be used. The most efficacious alternative for forest seedling nurseries in the southern United States is one that contains a significant percentage of chloropicrin as its active ingredient.

**Keywords:** soil fumigation, chloropicrin, loblolly pine, high barrier plastics, broadcast fumigation

## Introduction

Soil fumigation with methyl bromide (MBr) has been the standard method for producing high quality, pest-free forest seedlings in the southeastern United States. Methyl bromide has shown broad efficacy in the control of soil insects, nematodes, soil-borne pathogenic fungi, and problematic weeds such as nutsedge (*Cyperus* spp.). In the southern United States, *Fusarium*, *Pythium*, and *Rhizoctonia* are 3 fungal genera that are of primary concern in the production of pine seedlings, as they are associated with seedling root and foliage diseases. Over the years, MBr has been effective in controlling all 3 of these soil-borne pathogens in a wide variety of soil types.

Since soil fumigant alternatives vary in efficacy between nurseries, a description of forest seedling bareroot culture in the southern United States may be beneficial. Loblolly pine (*Pinus taeda* L.) is the primary tree species produced in southern forest seedling nurseries. Seeds are sown in mid-April and lifting begins in December of that same year. Soil pH ranges from 5.0 to 6.0, and soil organic matter from 0.8% to 1.9%. Most nursery soils are in the sandy-loam or loamy-sand classification. Generally, forest seedling nurseries operate on a 3-year cropping system with 2 seedling production years per soil fumigation. Fumigation can occur in either October or March. October fumigation provides a greater biological and operational window to obtain proper soil moisture and temperatures. The average nursery fumigates about 8 ha (20 ac) per year using a certified fumigation contractor. All fumigations are broadcast/flat fume using 4 m (13 ft) rolls of plastic glued together.

Due to the concern over ozone depletion in the stratosphere, the Montreal Protocol under the Clean Air Act began a phase-out program for MBr use in 1991. The Southern Forest Nursery Management Cooperative (SFNMC) began looking for alternative to MBr before the official phase-out program began, and this paper will outline the sequence of products tested and their results. While finding an alternative for MBr has been a priority within the forest seedling nursery industry, it has been difficult to find a soil fumigant that is as broad-spectrum as MBr.

Alternatives for MBr can be classified into 2 groups, that is, non-conventional and conventional. Non-conventional alternatives include: 1) solarization, that is, the use of solar energy to control soil pathogens; 2) biofumigation that uses gases from the biodegradation of organic matter; 3) hot water to heat the soil to temperatures that kill weeds, nematodes, and other organisms; and 4) other miscellaneous alternatives such as chicken litter, yard waste, crab processing residues, cricket litter, and the management of soil microorganisms. These non-conventional alternatives can be effective under limited conditions, such as small plots, but not for large acreage. SFNMC has not encouraged their widespread use. The second group would be considered conventional alternatives that include chemicals, both individual compounds and combinations. This latter group of alternatives has been the focus of the SFNMC research program because they are more easily adapted to large acreages.

The nursery industry realizes the importance of testing new fumigants, rates, and application techniques and, since 1972, the SFNMC and its cooperators have invested over US\$ 2.8 million in alternative research in 57 research studies in cooperation with many member nurseries. The largest number of studies has been undertaken in Georgia nurseries.

## 1970 to 1979—Decade of Methyl Bromide Acceptance

In 1975, a survey of 55 southern nurseries determined that 39 nurseries were using MBr, and 28 of those nurseries were fumigating on a yearly basis. During this decade, 10 studies were conducted in cooperation with the Weed Control Cooperative at Auburn University comparing herbicides with MBr.

MBr (98:2) (98% MBr plus 2% chloropicrin) was being used up to 504 kg/ha (450 lbs/ac) by most nurseries. At one nursery in Georgia, 1,3-dichloropropene (1,3 D) was tested. Research studies compared the economics of fumigation versus hand-weeding or herbicides for controlling weeds. Several interesting conclusions came from these studies:

- 1) Due to the low hourly labor cost, fumigation was not justified for weed control, unless nutsedge was a problem.
- 2) Control of nutsedge with MBr 98:2 at 497 kg/ha (444 lbs/ac) in the fall was recommended.
- 1) Supplementing soils with endomycorrhizae was justified if using MBr.
- 4) 1,3-D did not significantly reduce endomycorrhizae levels.
- 5) Alternatives were needed that would not reduce endomycorrhizae levels.

## 1980 to 1989—Decade of Herbicides

During the 1970s, the use of MBr became widespread and its broad efficacy was recognized and accepted in the production of forest seedlings. During the decade following 1980, the Nursery Cooperative did not conduct a single soil fumigation study. Research efforts instead focused on obtaining new herbicide registrations for use in nurseries over conifer seedlings. These herbicides included, Goal<sup>®</sup> (Dow AgroSciences LLC, Indianapolis, IN), Modown<sup>®</sup> (Makhteshim Agan Industries, Airport City, Israel), Poast<sup>®</sup> (BASF Corporation, Triangle Park, NC), Fusilade<sup>®</sup> (Syngenta Crop Protection Incorporated, Greensboro, NC), Roundup<sup>®</sup> (Monsanto Company, St Louis, MO), and Cobra<sup>®</sup> (Valent USA Corporation, Walnut Creek, CA), most of which are still being used in 2011. Nursery research also focused on increasing seed efficiency and seedling quality.

## 1990 to 1999—Decade of Losers and Winners

In the Spring 1992 issue of the SFNMC Newsletter, nurseries were notified for the first time that there was a chance of losing MBr due to Environmental Protection Agency (EPA) regulations mandating a MBr phase-out under the Clean Air Act. At that time, it was estimated that MBr would be phased out by the year 2000.

Chloropicrin was recognized as a possible MBr alternative, but required additional research. While the compound had been shown to be efficacious on soil-borne fungi, insects, and nematodes, the compound was not as effective on weeds, especially nutsedge.

In 1993 and 1994, small plot alternative research trials were established to compare dazomet, chloropicrin, metham sodium with and without chloropicrin, and 1,3-D in addition to soil bio-amendments. In some studies, high density plastic tarps (HDPE) were used, and in other cases no tarp was used. As a result of these studies, applications of less than 280 kg/ha (250 lbs/ac) chloropicrin or less than 314 kg/ha (280 lbs/ac) dazomet were not recommended. Metham sodium produced seedlings similar in quality to those grown in MBr-treated soil. There was no significant difference in the results whether HDPE tarps were used or not. Dazomet reduced the beneficial soil fungus

*Trichoderma* in one trial by 91%; chloropicrin more than doubled *Trichoderma* in other trials. These studies were the first to indicate that dazomet resulted in variable seedling quality and fungal control and was therefore not a strong alternative. Nurseries were strongly encouraged to plan alternative soil fumigant trials and evaluations in their own nurseries before the final phase-out of MBr.

In 1994, a fumigation trial using hot water was established in Camden, AL. Hot water at 43 °C (110 °F) was shank-injected and mechanically mixed in the soil up to 15 cm (6 in). This process used the equivalent of 345,830 l/ha (37,000 gal/ac) of water traveling at 0.8 km/hr (0.5 mi/hr) and produced inconsistent soil temperatures. The amount of diesel fuel required to heat this water was not reported. As a result, the Nursery Cooperative recognized that this was not a viable large-scale alternative to MBr.

By spring 1996, only 30% of nurseries in the southern US fumigated their soils following every crop, and 66% fumigated every 2 or more seedling crops. Alternatives that appeared to be effective were: chloropicrin; chloropicrin plus 1,3-D; and metham sodium plus chloropicrin both tarped and untarped. There was still concern about weed control using these alternatives. The SFNMC therefore began evaluating EPTC (Eptam<sup>®</sup>; Gowan Company, Yuma, AZ ) for nutsedge control at 6.72 kg ai/ha (6 lbs ai/ac) rotovated through 15 cm (6 in) of soil. Initial results showed good weed activity. By the end of the decade, however, the use of EPTC diminished due to the stunting of seedlings (carry-over) and the necessity to rotovate this product into the soil. Soil fumigation applicators did not have the equipment to both rotovate EPTC and simultaneously inject soil fumigants using 4-m (13-ft) broadcast tarp applications.

Between 1997 and 1999, the Nursery Cooperative was optimistic with research using chloropicrin in combination with metham sodium and believed that this combination could be used without a tarp. By not using a plastic tarp, the additional problem of disposing of the tarp following fumigation was avoided.

The optimism was short-lived. In the fall of 1999, a nursery in Texas fumigated more than 4 ha (10 ac) with metham sodium plus chloropicrin without a tarp. Following a temperature inversion that night, the fumigant did not dissipate in the atmosphere but rather settled onto areas of adjacent seedlings ready to be lifted. More than 20 million seedlings were killed that evening. As a result, all non-tarped soil fumigation applications were halted.

## 2000 to 2010 — The Decade of Chloropicrin

During the early years of this decade, the dazomet manufacturers changed their protocol in an attempt to identify a treatment that would provide consistent results in southern US nurseries. Further tests continued with metham sodium plus chloropicrin and metham potassium plus chloropicrin. Studies also examined shank injected and tarped applications of methyl iodide plus chloropicrin, methyl iodide, and Telone C-35<sup>®</sup> (65% 1,3-D plus 35% chloropicrin).

The results of these studies showed metham sodium, 1,3-D, and dazomet were marginally better than methyl iodide and metham potassium. The high cost of methyl iodide (nearly five times that of MBr and chloropicrin mixtures) was a concern to nursery managers. Telone C-35<sup>®</sup> provided good nematode control and enhanced weed control. Although metham sodium plus chloropicrin showed promising results, both metham sodium and metham potassium were dropped from further testing due to application difficulties. Broadcast/flat tarp fumigation equipment technology would not allow a one-pass rotovation plus shank injected fumigant followed by the standard 4-m (13-ft) tarp application. Until market forces bring about new application technologies, all broadcast alternatives that require some sort



of rotovation will not be part of the MBr alternatives used in forest seedling nurseries in the southern US.

In 2003, the first small test plots using high barrier plastic tarp (virtually impermeable film [VIF]) were established. Due to the inability to glue consecutive strips of VIF using conventional HDPE plastic glue, both ends of the tarp were buried in the ground. A new chloropicrin formulation, PIC+<sup>®</sup>, that was 85% chloropicrin plus 15% solvent was also evaluated. This formulation of chloropicrin with a solvent performed similarly to a slow-release fertilizer, keeping the chloropicrin in the soil for a longer period of time. The presence of a tarp improved the efficacy of nutsedge control using PIC+<sup>®</sup>. There was no difference in weed control between PIC+<sup>®</sup> and chloropicrin. Chloropicrin and PIC+<sup>®</sup> also enhanced *Trichoderma* in the soil. These studies suggested that application rates of MBr and chloropicrin could be reduced by as much 50% when using high barrier plastics.

In 2004, dimethyl disulfide (DMDS) was first tested. Seedling quality and the amount of *Trichoderma* in soils treated with this new compound were equal to MBr. DMDS, however, had an unpleasant smell, described as similar to propane, which remained in the soil for most of the growing season.

In 2005, 2 fumigation studies were established that would evaluate fumigant efficacy over 2 growing seasons. The first trial in Georgia compared both methyl iodide and MBr under both VIF and HDPE plastic with dazomet using another new protocol and a water seal. The results of the 2-year study showed methyl iodide had more weeds than other fumigants tested. The seedling quality with methyl iodide was similar to MBr. Seedling quality using VIF was similar to that using HDPE at twice the fumigant rate. At the end of the first growing season, seedlings that received dazomet never grew tall enough to be top clipped. At the end of the second growing season, only seedlings in the edge drills of the beds were top clipped. In addition, *Trichoderma* counts for the dazomet plots were the lowest compared to other treatments. During the third year, a cover crop of corn was sown in the test area, and corn sown in the dazomet plots had extremely low germination.

A second 2-year fumigation study was established in Texas testing Chlor 60<sup>®</sup> (60% chloropicrin plus 40% 1,3-D), PIC +<sup>®</sup>, 100% chloropicrin, and dazomet. At the end of both the first and second growing seasons, the PIC+<sup>®</sup> plots were visibly taller than any other soil fumigation treatment. Other seedling quality data confirmed that PIC+<sup>®</sup> was the best alternative in this study. Dazomet again produced the lowest quality seedlings in both growing seasons. Following the results of these two studies, the decision was made to stop further testing of dazomet as an alternative to MBr.

**Table 1.** Fumigant tested, rates, plastic tarps, and number of research studies.

Fumigant	Rate (metric)	Rate (Imperial)	Components	Plastic <sup>1</sup>	#of studies
Chloropicrin	336, 280, 168, 112 kg/ha	300, 250, 200, 150, 100 lbs/ac	100% chloropicrin	HDPE, LDPE, VIF, TIF	7
Pic+ <sup>®</sup>	336 kg/ha	300 lbs/ac	85% chloropicrin plus 15% Solvent A	HDPE, LDPE, VIF, TIF	7
New Pic+ <sup>®</sup>	336 kg/ha	300 lbs/ac	85% chloropicrin plus 15% Solvent B	HDPE	2
DMDS + Chlor	690, 653 l/ha	74, 70 gal/ac	79% DMDS plus 21% chloropicrin	HDPE	5
Chlor 60 <sup>®</sup>	336, 280, 168, 112 kg/ha	300, 250, 200, 150, 100 lbs/ac	60% chloropicrin plus 40% 1,3-D	HDPE, LDPE, VIF, TIF	7
Midas <sup>®</sup> 50/50	179 kg/ha	160 lbs/ac	50% methyl iodide plus 50% chloropicrin	VIF	1
Midas <sup>®</sup> 98/2	112 kg/ha	100 lbs/ac	98% methyl iodide plus 2% chloropicrin	VIF	1

<sup>1</sup>LDPE = low density polyethylene; HDPE = high density polyethylene; VIF = virtually impermeable film; TIF = totally impermeable film.

Beginning in 2007, the MBr alternative research program of the SFNMC began focusing on replicated large plot studies (greater than 1.6 ha [4 ac]), testing of similar alternatives (when possible) in different nurseries (Table 1), and the collecting of similar data (Table 2) over 2- to 3-year growing cycles.

This new research approach was taken with the assistance of a 5-year grant from a USDA Agricultural Research Service South Atlantic Area-

**Table 2.** Seedling quality parameters measured and frequency.

Seedling Parameter	Frequency
Root collar diameter	at lifting
Height	at lifting
Seedling density	2 times/season
Soil assay for Nematodes	2 times/season
Soil assay for <i>Trichoderma</i>	2 times/season
Seedling biomass	at lifting
Root architecture:	
Root length	at lifting
Root diameter	at lifting
Root volume	at lifting
Root tips	at lifting

wide Pest Management Program for Methyl Bromide Alternatives. This grant allowed the SFNMC to have yearly replicated studies across nurseries in the southern US. The data collected through this project has been used by EPA in their evaluation of the criteria needed for the soil fumigant Re-registration Eligibility Decisions (REDs).

During the first year of this project, a new soil fumigant was tested. New PIC+<sup>®</sup> was a re-formulation of Pic +<sup>®</sup> but containing a different solvent. This fumigant produced similar seedling characteristics, control of nematodes and soil-borne pathogens, and *Trichoderma* levels to that of Pic+<sup>®</sup>, but resulted in a significant annual sedge (*Cyperus compressus*) problem. Because of the weed pressure when this compound was used, it was subsequently dropped from the program after 1 year.

One of the limiting factors in broadcast soil fumigations has been the inability to glue 2 pieces of impermeable film together along the seams to form an air-tight barrier. Since the beginning of the USDA ARS Areawide project in 2007, the largest private fumigation contractor in the southern US developed new technologies for gluing the high barrier plastic films used in broadcast fumigation. This glue tech-

nology will allow forest seedling nurseries to use high barrier plastics and thus significantly reduce the amount of soil fumigants used. The use of the high barrier plastics will also increase soil fumigation efficacy by allowing the soil fumigant to remain in the soil at a higher concentration and possibly over a longer period of time. By reducing application rates, the buffer zones associated with the new EPA soil fumigant labels will also be reduced, allowing greater access to nursery operations.

Research by the SFNMC to date has shown that there are 3 competitive alternatives available for nursery use: Pic+<sup>®</sup>, 100% chloropicrin, and DMDS plus chloropicrin. These choices were made based upon overall seed efficiency, seedling quality at the end of the growing season, root biomass and morphology, *Trichoderma* levels after fumigation, with no excessive nematode or weed problems.

Several other points should be considered when using these MBr alternatives. They all need to be used with high barrier plastics, either totally impermeable film (TIF) or VIF. Chloropicrin needs to be applied at minimum rate of 280 kg/ha (250 lbs/ac). Although DMDS is a decent alternative, the strong, lingering odor may limit its use and acceptance by nursery managers. Chlor 60<sup>®</sup> was an effective alternative in most nurseries with respect to seedling quality and would be recommended to nurseries with a nematode problem. Weeds may become an issue with Chlor 60<sup>®</sup> if managers do not aggressively control them. We have not had sufficient experience to adequately evaluate Midas<sup>®</sup> (methyl iodide). Arista Life Science, the manufacturer of Midas<sup>®</sup>, has not fully cooperated with our efforts to further evaluate methyl iodide in southern forest seedling nurseries. The manufacturer has not been willing to extend research studies much beyond Florida. The cost for a nursery to put in a study with methyl iodide is US\$ 12,350/ha (US\$ 5,000/ac), a minimum of 8 ha (20 ac), and the nursery is responsible to remove all tarps. In June 2011, EPA opened up a new comment period to examine some concerns of methyl iodide; it is therefore possible that this compound may have its label revoked.

## Summary

After more than 35 years of MBr alternative research, we have reached the following conclusions:

- 1) Soil fumigant alternatives to MBr exist.
- 2) We have yet to find an alternative as efficacious as MBr.
- 3) Any choice of current alternatives will most likely require an increased use of pesticides (especially herbicides) to compensate for alternative short falls.
- 4) We do not know the long-term benefits of the alternatives. That is, what will happen in 4 or 5 fumigation cycles without MBr?
- 5) MBr is highly efficacious under many soil types and environmental conditions; however, alternatives do not have the same physical and chemical properties as MBr. Nurseries must pay close attention to factors such as soil moisture and temperature when using alternatives.
- 6) An effective alternative in one nursery may not be as effective in another nursery. All nurseries should be testing alternatives at varying rates whenever possible.
- 7) The most significant development in alternative research in the last 5 years has been the availability of high barrier plastics (TIF and VIF) and the technology to glue this plastic for broadcast fumigation applications.
- 8) When transitioning from low barrier plastic such as HDPE to high barrier plastics such as TIF and VIF, fumigation rates can be reduced by half. This recommendation should be used with caution because fumigant efficacy varies between nurseries.

- 9) An alternative becomes more efficacious when chloropicrin is part of the formulation at rates above 20%, for example: 1) DMDS versus DMDS plus chloropicrin (Paladin<sup>®</sup>); 2) methyl iodide versus methyl iodide plus chloropicrin (Midas<sup>®</sup>); or 3) Telone<sup>®</sup> versus Telone<sup>®</sup> plus chloropicrin (Chlor 60<sup>®</sup>).

## Future Research with Alternatives

With EPA buffer zone restrictions coming into place in 2012, low barrier plastics (HDPE and LDPE) will become used less frequently. Since high barrier plastics (VIF and TIF) cost significantly more than low barrier plastics, fumigation costs can be reduced by decreasing the amount of soil fumigant used. In the future, we can expect new plastic technology for controlling emission rates. Although effective, high barrier plastics like TIF have been criticized for not allowing any gas to permeate through the barrier, thus potentially creating a problem when the tarps are cut for removal after 10 to 14 days. New, untested soil fumigants will be harder to register in the future than compounds already labeled and in the market. For example, SFNMC was evaluating sulfuric fluoride as a soil fumigant until EPA expressed concern over the release of fluoride into the environment. Opportunities exist for new application technologies to be developed in broadcast fumigation that would allow a combination rotovator/injector/flat tarp applicator or a combination potassium thiosulfate applicator/injector/flat tarp applicator. There is also a need to explore changes in fumigant chemistry that will allow injections of several fumigants in a single pass, that is, using existing application techniques similar to tank mixing pesticides to make them more efficacious. Nurseries also need to look at current management practices that can be altered to reduce the impact of buffer zones (reduce emissions). For example, increasing soil organic matter will make seedling management easier and will provide additional buffer zone credits for fumigation.

During the last few years, the ability to use soil fumigation in forest seedling nurseries has dramatically changed. The future does not look optimistic for increasing the use of soil fumigants. The choices for viable alternatives will most likely be limited and decrease as each soil fumigant is reexamined again in 2013 for registration. The forest seedling nursery community must stay aware of regulatory changes that may impact future soil fumigation. For example, there was discussion concerning the possible elimination of chloropicrin as a soil fumigant. This idea was dropped for now. If it ever becomes an issue, there needs to be a unified response from the nursery community against any effort to eliminate chloropicrin. Chloropicrin is part of every efficacious fumigation alternative the forest nursery industry has.

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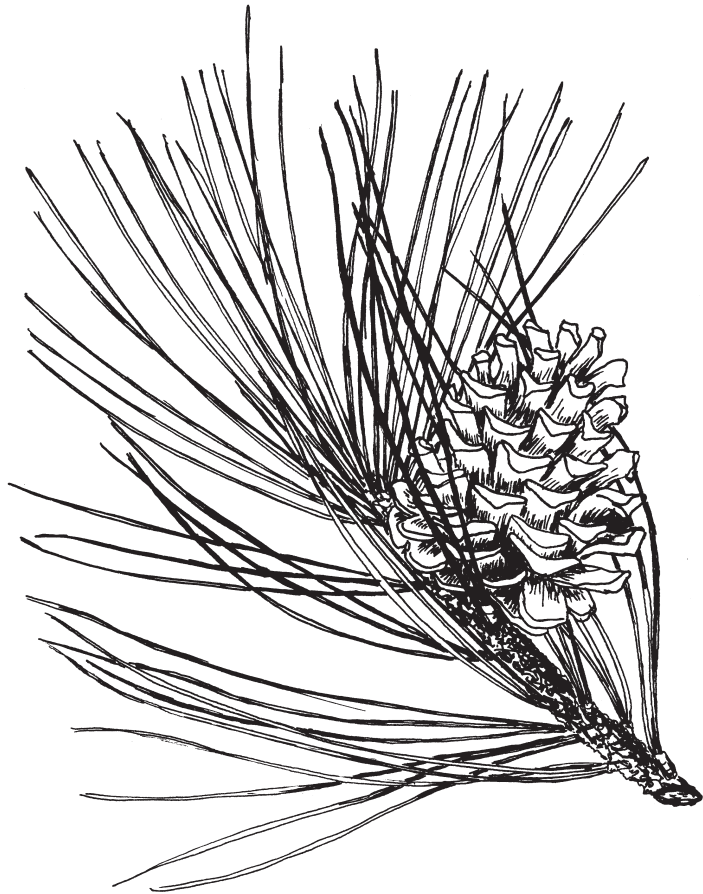
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# Western Forest and Conservation Nursery Association Meeting

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*Ponderosa pine drawing by Lorraine Ashland, College of Natural Resources, University of Idaho*

# Developing Native Plant Nurseries in Emerging Market Areas

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Duemler E. 2012. Developing native plant nurseries in emerging market areas. In: Haase DL, Pinto JR, Riley LE, technical coordinators. National Proceedings: Forest and Conservation Nursery Associations—2011. Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. Proceedings RMRS-P-68. 39-40. Available at: [http://www.fs.fed.us/rm/pubs/rmrs\\_p068.html](http://www.fs.fed.us/rm/pubs/rmrs_p068.html)

**Abstract:** The importance of developing a market for quality native plant materials in a region prior to the establishment of a nursery is crucial to ensure its success. Certain tactics can be applied to help develop a demand for native plant materials in a region. Using these tactics will help create a new market for native plant materials.

**Keywords:** Native plants, native seed, sales, marketing

## Introduction

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Applied Ecological Services, Inc. (AES) has established native plant and seed nurseries in 5 separate locations: Minnesota, Wisconsin, Indiana, New York and Kansas. Each location is a different market, and each has varying levels of market maturity. The operations vary in size and services offered but at a minimum, provide native plants or seed. Through this experience, AES has identified basic strategies to help build the need for more native plant and seed products. We feel that these strategies can be applied by any group, anywhere, to help build a stronger market for native plant materials.

For any successful restoration project, it is important to have locally available, genetically appropriate native plant products. It is our observation that areas with a good supply of native plant materials are typically in regions with an established ecological consulting presence; however, having the consulting presence alone, does not drive the need for the plant materials. Of course, habitat loss and land degradation near population centers are the primary drivers behind the need for native plant materials. Other factors such as strong contractual specifications, the ability of consultants to hold contractors to the specifications, public awareness of native plants, land conservation history in the region, and consistent failures of conventional methods to solve complex problems can also drive the need for quality native plant materials.

## Methods

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One of the primary methods to develop an increasing need for native plant materials is education. It is absolutely critical to make the public and professionals aware of the importance of native plants and the restoration process. Designers would otherwise find it difficult to apply natural processes in built environments without the approval of either of these groups.

Educating the public on restoration can come through several facets. Simple things such as, signage on established native landscaping and restoration projects or brochures explaining the use of native plants in the landscape can be very helpful to show the public what to expect. Helping the public make a paradigm shift from expecting mowed turf grass lawns to sustainable landscapes is the most important part of the process. If the public does not understand and accept the importance of native plants, and consequently demand their use, professionals will see no need to incorporate them in their designs.

## Educating the public

Increasing public awareness is the most important part of creating demand for native plant materials. This can be done through several methods.

1. Publications. Publications should be informative and describe any of the following: how the restoration process works; the best utilization of native plants in the landscape; or the benefits of native plants compared to non-natives.
2. Demonstrations. Public botanical gardens are a great place to install native plant demonstrations or trials. Many botanical gardens are already interested in native plants, and if they haven't already, are usually interested in setting these up. Demonstrations are particularly helpful because they help people visualize how natives are used in the landscape.
3. Persistence. Developing a market for native plant materials may not happen quickly or easily. One must be persistent and opportunistic to educate and demonstrate the importance of native plants to the public.

## Influencing design professionals

It is important for design professionals to fully understand how to use natives in order to have successful restoration projects. They often need to know basic information such as stocktype and species availability. As a local plant and seed supplier, you are the expert with the materials you grow, and it is your responsibility to educate designers. Unfortunately, it is common to see contracts that have native seed and plant specifications that are unrealistic. These poor specifications can lead to frustration for the contractor and ultimately contribute to project failure. If designers have the right information ahead of time, they can avoid these problems during construction. Regional native plant nursery producers should make available to designers information on:

species availability, stocktype availability, and basic plant requirements such as sun, soil, moisture, growing space, and plant phenology. Even this small amount of information will help designers avoid using the wrong plant in the wrong situation. Putting the right plant in the right place is crucial for the project success.

Along with helping design professionals better understand the product, it is also important for them to understand the native vegetation establishment process. The Target Plant Concept (Landis 2011) helps with this by covering information about a project from planning to planting. This includes understanding localized processes such as moisture trends as well as outplanting windows—critical factors in seedling establishment. As well, it is likely there are local publications that will provide helpful information. Armed with this information, designers can better educate their client and increase their chances of success.

## Summary

If you are in a region where the native plant market is weak or does not exist, implementing some or all of these techniques should help increase the demand for native plant materials. The underlying theme of developing a market for native plant materials is education. Regardless of your affiliation, public or private sector, if you want to see your region develop a stronger native market, it is important to be persistent. In the end, by using native plants for restoration, we hope to be good stewards of the land, public or private.

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# Roots of Success: Marketing Strategies for the 21st Century

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Doescher I. 2012. Roots of success: marketing strategies for the 21st century. In: Haase DL, Pinto JR, Riley LE, technical coordinators. National Proceedings: Forest and Conservation Nursery Associations—2011. Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. Proceedings RMRS-P-68. 41-44. Available at: [http://www.fs.fed.us/rm/pubs/rmrs\\_p068.html](http://www.fs.fed.us/rm/pubs/rmrs_p068.html)

**Abstract:** As the demographic of gardeners and farmers changes, retail nurseries should update their marketing approach. This paper reviews best marketing practices and discusses marketing technologies, including quick response (QR) codes, websites, online marketing, and social media.

**Keywords:** social media, Facebook, QR codes, website, online marketing

## Introduction

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A new generation of consumers—young adults in their 20s and 30s—is reclaiming traditional homemaking skills in large numbers. These skills are familiar to their grandmothers' generation, although they may have skipped over their mothers' generation, and they include knitting, canning foods, gardening, and farming. According to a 2009 National Gardening Association study, people ages 18 to 34 now comprise 21% of the total gardening population (National Gardening Association 2009). This number continues to grow. In her book *Radical Homemakers*, author Shannon Hayes writes, "*Radical Homemakers* simultaneously build a life-serving economy while reducing their reliance on the extractive economy... The seasoned homemaker takes joy in teaching gardening and food preservation, or sharing any other myriad skills with her neighbors, both building her community's capacity to provide for itself and stimulating her own intellect" (Hayes 2010).

As a new generation of consumers emerges, retail nurseries must adapt their marketing strategies to reach younger audiences. This paper will review best marketing practices, and discuss emerging marketing technologies including quick response (QR) codes, websites, online marketing, and social media.

## Best Marketing Practices

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### Copy: Words that Do (and Don't) Work

Words that work:

- 1) Free. Decades ago, when marketing maven Victor Schwab analyzed 100 great advertising headlines, he wrote, "'Free' is, of course, a hackneyed and moss-covered word, but there doesn't seem to be any equally strong, or less blatant, substitute for it" (Schwab 1985). When you have something to offer, "free" is a handy word in your copy toolbox.
- 2) Positive content. Positive words and messages are much more attractive to readers than negative content. Tell a positive story, offer a hopeful phrase, inspire your audience, or just make them smile.

- 3) How and why. Consumers like finding out the answers to questions, learning new things, and getting an inside scoop. Copy that promises to answer a question—to teach people how to do something, how something works, why something matters, or why they should do something—is a compelling hook.

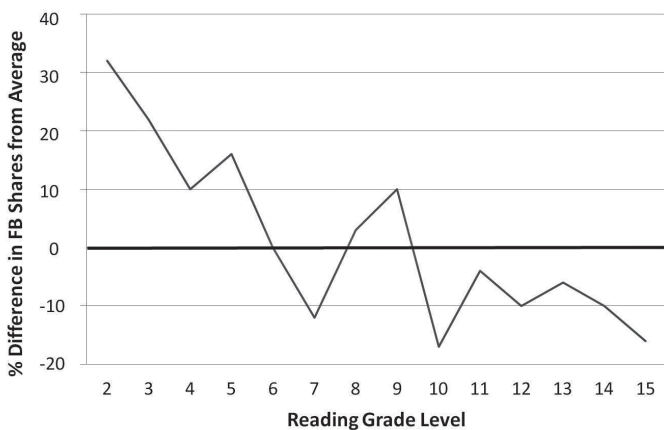
Words that don't work in marketing copy:

- 1) Technical language. Industry-specific words may not be the right words for your marketing materials, particularly if they are words that only a few people know. There is no need to talk about embryos, angiosperms, and gymnosperms when you can just as easily talk about seeds.
- 2) Complicated language. Zarrella (2010) showed that the most popular writing online was written at a ninth grader's reading level or lower. Even more popular was language written at a second or third grade level (Figure 1). This doesn't mean consumers are dumb, just that your copy should be simple and to the point.
- 3) Vague copy. The more specific your content is, the more likely your audience is to read it. For instance, an article on "How to be successful in business" is less compelling than an article on "How to lift your business out of debt." Your copy should be focused, addressing a specific need or answering a specific question rather than speaking in generalities.

## Design: What to Remember When Creating Your Ads

Following these best practices of design will help you create effective ads and other materials.

- 1) Make your design clear. If things in your ad look too cluttered to you, they definitely will to potential customers. Don't feel the need to say everything about your plants, trees, and other products at once.
- 2) Use white space effectively. The eye needs white space to make sense of content and to process text and images. Instead of trying to use every last bit of your available space, give your design some breathing room by leaving areas of white space in your design.
- 3) Tell a story. Recent marketing studies show that the most effective ads are those that tell a story. Stories engage viewers' imaginations and invite them to imagine themselves as part of the story. Remember also that stories aren't just written text—stories can be told through images.



**Figure 1.** Percentage, above or below average, of Facebook posts that were shared (re-posted) based on reading grade level of the post (modified from Zarrella 2010).

- 4) Stay true to your brand. Your materials should have a look and feel consistent not only with each other but also with the brand you have established. Remember that your brand is more than your logo or your typical ad colors—your brand is all about how people perceive you. So if you're the hippest nursery around, your ads should reflect that. If you're known for being a family business since 1895, your ads should reflect that.
- 5) Double check your spelling and grammar. At best, spelling and grammar mistakes are embarrassing. At worst, they make your audience think you don't care—so why should they? Remember that your computer's spell check doesn't catch everything, so giving your materials a second glance with an eye toward spelling and grammar is important.

## Emerging Marketing Strategies Quick Response Codes

The first emerging marketing strategy this paper will discuss is QR codes (Figure 2). These codes refer to two-dimensional (rather than traditional one-dimensional) barcodes. Whereas a traditional UPC (Universal Product Code) encodes 10 digits, QR codes are capable of holding over 7,000 numbers or over 4,000 alphanumeric characters. QR codes can encode information like product information, web addresses, and more.

UPCs have traditionally only been readable by special scanners (and number nerds). By contrast, QR codes can be read by a QR code scanner or by most cell phones with a camera. Since their introduction, QR codes have been used in marketing campaigns for everything from movies to sporting goods, cell phones to restaurants. QR codes have been printed on posters and in magazines, but also in public places like the sides of buildings. Any cell phone user spotting such a QR code can use their phone to read the code and receive a message, be taken to a website, make a call to a special phone number, and so on.

Free online generators allow you to create QR codes capable of performing a number of functions:

- 1) A QR code that stores an URL (web address) takes the person who reads the code with their smartphone directly to the encoded website;
- 2) A QR code that stores a phone number automatically places a call to the phone number encoded in the QR code;
- 3) A QR code that stores text displays the encoded message on the user's phone;



**Figure 1.** A sample quick response (QR) code.

- 4) A QR code that stores a phone number and text message (SMS), sending the encoded text message (up to 160 characters long) to the encoded phone number.

QR codes represent great potential for marketing your business and easily attaching information to your products. This technology is growing in popularity and may be a way to bring a quick response to your creativity.

## Websites

In the year 2011, the power and ubiquity of websites is well-known. While most nurseries have websites with fine designs, a website needs frequent refreshing. Listed below are some simple ways to refresh your site:

- 1) Update news and events. Make sure your online calendar or other list of events is current and highlights future (not past) items.
- 2) Rewrite copy. Reread the copy you originally wrote for your website and revise as needed. Fresh content on a website helps search engines see that your website is active and well-used; this will improve your search engine rankings. Rewriting copy can also give repeat site visitors a better experience as they find a new message greeting them.
- 3) Update images. Replacing images on your website that are old or have been on the site for a long time is a simple way to update the look of your site. As a general rule, you should replace any photo older than a year.
- 4) Link to social media. The home page of your website should feature and link to your social media sites. If possible, integrating social media sites in your internal pages—adding Like or Tweet buttons, for instance—is another way to engage users as they visit your site.

## Online Marketing

Online advertising has become a key piece of most marketing campaigns. Generally, online marketing falls into two categories: social media marketing and search engine marketing.

- 1) Social media marketing refers to placing ads on social media sites like Facebook. Social media marketing is a powerful tool, because ads can be targeted based on the profiles users have created. Facebook ads are currently the most popular forum for social media marketing, allowing you to target ads to specific people based on location, gender, age, interests, and so on. For example, you can target your ad to people within 10 miles of Smallville whose interests include gardening. Facebook will tell you how large your proposed list is. Then you design your ad and tell Facebook how you want to pay for it—by impressions (number of times your ad is shown) or actual click-throughs (number of times people click and go to your site). You can also automatically limit the amount you spend if desired. LinkedIn© and other social media services offer similar advertising options.
- 2) Search engine marketing can refer to ensuring your search engine optimization (SEO) is fresh, but it also refers to placing ads with search engines. When you perform a search online, you see sponsored links on the side or the top of the results. Those links are there because those companies paid to be featured as “sponsored” results. This is search engine marketing—paying a search engine to list you as a sponsored link for certain words or phrases. This can be as straightforward as paying Bing™ to list you as a sponsored link for a keyword phrase that describes your company, or as com-

plex as paying search engines to show your ad for keywords that aren’t necessarily related to your company.

Both social media marketing and search engine marketing should be an aspect of your marketing campaigns in 2011 and beyond.

## Social Media

The rise of social media services like Twitter and Facebook—that currently have over 800 million users worldwide—has made social media an area marketers should not avoid. Social media sites allow companies to create business profiles, attract “likers” and followers, and spread the company’s message to those people. Following are some of the best practices of social media:

- 1) Write a social media strategy. Your strategy should answer at least five questions:
  - a) What is our company’s goal for using social media?
  - b) Which sites should we use?
  - c) Who will keep the content fresh?
  - d) Who is our audience for social media?
  - e) How will we promote our social media presence?
- 2) Avoid using too many social media sites. When you are spread across too many social media sites, it is difficult to have an effective and engaging presence in every place. Instead, focus on one or two sites that will be most useful. Facebook is likely to be one of these sites for two reasons: 1) Facebook’s reach is more extensive than any other social media site; and 2) Facebook enables you to use various types of media and expressions.
- 3) Keep content engaging and current. Keeping the content on your social media pages fresh is as important as being on social media in the first place: don’t do one without the other. For Facebook, this means posting something daily (at best), or at least once a week. Also, make sure your content is engaging—give your likers and followers a reason to stay connected to you. You can do this by letting your personality show, offering insights and deals exclusive to your social media connections, posting photos and videos, and generally making your page an interesting place to be.
- 4) Attempting to control the conversation is unacceptable. Most social media sites give people a way to respond to you publicly. People expect to have a voice on social media, even on someone else’s social media page. It may be difficult to read negative comments, and there are various strategies for moderating those, but controlling the conversation is considered unacceptable in the realm of social media.
- 5) Respond promptly when people comment on your social media site. Make sure your social media sites are monitored regularly so quick responses can be made. The response can often be as simple as, “Thanks for letting us know,” or “We’ll have someone contact you about that as soon as possible,” but do respond quickly.
- 6) Overselling on social media may be the quickest way to get people to stop liking you or following you. If you are going to sell your products or services through social media, consider offering a special deal to your social media connections. Tweeting a special 25% coupon code on your widgets offers more value than simply tweeting, “Did you know we sell widgets?”

These social media best practices will help you avoid some common pitfalls. Remember that the ultimate value of social media is in cultivating relationships with your customers and prospects.

## Conclusion

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Updating your marketing approach for the 21st century is vital for nurseries who wish to reach the next generation of gardeners and farmers. Using the best practices and emergent marketing technologies described in this paper, you will see greater marketing success and improved sales.

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# Using Organic Fertilizers in Forest and Native Plant Nurseries

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**Abstract:** Since World War II, synthetic fertilizers have been used almost exclusively to grow forest and native plant nursery crops because they are quickly soluble and readily taken up by crops, producing the rapid growth rates that are necessary in nursery culture. In recent years, however, a wide variety of new organic fertilizers have become available. We divided these organics into three categories: 1) animal and plant wastes that are sustainable, and can further be separated into unprocessed and processed materials; 2) natural minerals that are unsustainable, with their use regulated in strict organic farming; and 3) a blend of waste material supplemented with natural minerals. Mineral nutrients are released more slowly by organic fertilizers and crops will therefore take longer to reach commercial size. This slow nutrient release rate has other benefits, however, such as less chance of water pollution and better establishment of beneficial microorganisms. In the final analysis, high quality nursery crops can be grown with organic fertilizers, but production schedules will have to be adjusted.

**Keywords:** nutrient release rate, nutrient uptake, nutrient analysis, pollution, mycorrhizae

## Introduction

Until the early 20th century, nearly all fertilizers used in agriculture, including nurseries, were organic. Animal manure and compost were the primary fertilizers mentioned in the first USDA Forest Service nursery manual (Tillotson 1917). Prior to World Wars I and II, Chilean nitrate was the main source of organic nitrogen; demand for nitrogen that was essential for the manufacture of munitions, however, quickly outpaced availability (Wikipedia 2011b). This led to development of the Haber-Bosch Process that converts the abundant nitrogen gas in our atmosphere into ammonia; this ammonia can then be chemically converted into a vast array of synthetic fertilizers (Meister 2011). After World War II, these synthetic, ammonia-based fertilizers became cheap and readily available, and use of organic fertilizers dropped from 91% in the early 1900s to 3% by the 1950s (Jones 1982). In recent decades, organic farming has seen a resurgence due to changes in public values and greater availability of new types of organic fertilizers. We therefore believe it is time to take a second look at how organic fertilizers could be utilized in forest and native plant nurseries.

## What is an Organic Fertilizer?

Standard agriculture or horticulture fertilizer references, such as Jones (1982) or the California Plant Health Association (2002), offer no practical definition for organic fertilizers and only contain a couple of paragraphs on organic amendments. After spending a considerable amount of time researching the topic, we found that the lack of information is due to the fact that organic fertilizers are a very complicated and confusing subject.

Part of the confusion is the result of terminology. In chemistry, an “organic” compound is one that contains carbon; this really doesn’t have anything to do with organic fertilizers. When dealing with food production, the term organic has a legal definition; a private, non-profit organization, known as the Organic Materials Review Institute, evaluates fertilizers for certified organic food production (OMRI 2011). Because we are not growing edible plants, forest and native plant nurseries are not bound by these regulations.

## Organic Fertilizers Types

For the purposes of our discussion, organic fertilizers can be defined as materials that are naturally occurring and have not been synthesized. We divided organic fertilizers into three general categories: 1) animal or plant wastes; 2) natural minerals; and 3) blended wastes supplemented with natural minerals (Figure 1).

### Animal or Plant Wastes

Animal and plant wastes are the materials that most people consider to be organic fertilizers. These materials can be applied to crops directly or developed into a wide variety of other processed fertilizers. One of the real attractions of these types of organic fertilizers is that they are sustainable and widely available; on the other hand, heavy use of animal manures poses a potential source of water pollution (Moral and others 2009).

### Unprocessed Organic Wastes

Unprocessed organic wastes are by far the largest and most complicated; almost any type of organic matter has been used as a fertilizer, including animal manure, sewage sludge, peat moss, hopwaste, and a myriad of composts. The best criteria for determining what types of organic matter can be considered fertilizers is their carbon-to-nitrogen (C:N) ratio (Landis 2011). Organic materials with a C:N less than 10:1 are considered to be fertilizers.

Evaluating the fertilizer benefits of unprocessed organics is extremely difficult because these materials have many other beneficial effects on crop growth and yield besides simple nutrition (Benzian 1965). For example, animal manure can be a source of all essential plant nutrients, but its organic matter also improves the tilth, aeration, and water-holding capacity of the soil, and stimulates beneficial soil microorganisms. Unprocessed organic wastes can be challenging to use because of their high potential for water pollution. When growing organic vegetable crops, composted manure is not recommended

because of potential leaching of high levels of phosphorus, one of the leading causes of water eutrophication (Sharpley and others 1994).

Although raw organic materials, such as manure and compost, were considered the “most useful fertilizers” in historical times, they are not commonly used in contemporary forest nurseries (Armson and Sadreika 1979; van den Driessche 1984). Green manure crops that have been used for centuries to capture mineral nutrients are also not recommended for forest nurseries because of concerns about disease pathogens (McGuire and Hannaway 1984). For those interested in more information on using raw organic materials in bareroot nurseries, a wealth of published information is available (Chaney and others 1992; Rose and others 1995; Card and others 2009).

### Processed Organic Wastes

Processed organic wastes are considered to be any organic material that has been processed in some manner before being used as a solid or liquid fertilizer (Figure 1), including composts, bloodmeal, bone meal, sewage sludge, as well as more exotic materials such as feather meal and kelp extracts. Almost any waste organic matter can be composted, and the composting process has been well documented (Landis and Khadduri 2008).

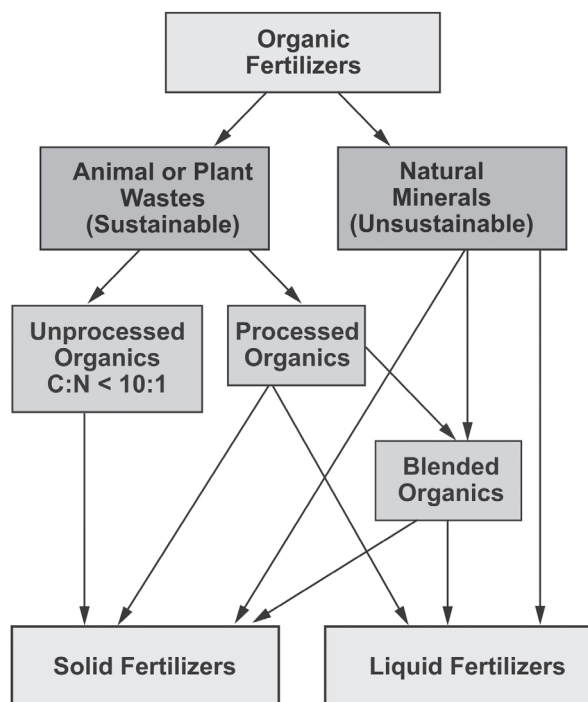
Although processed organic fertilizers are common in organic farming, they have not been widely used in forest or native plant nurseries. Many new processed organic fertilizers, however, are now available from horticultural supply firms. For example, Bradfield Organics® fertilizers (available through Hummert™ International, Earth City, MO) are marketed for specific crops, such as lawns or vegetables. Their Luscious Lawn Corn Gluten (9N:0P<sub>2</sub>O<sub>5</sub>:0K<sub>2</sub>O) Organic Fertilizer is made from the wet milling processing of corn and comes in an easy-to-apply granular formulation. Interestingly enough, corn gluten has also been shown to have pre-emergent herbicidal effects on some grasses (Christians 2011).

### Natural Mineral Fertilizers

Natural mineral fertilizers are a second major category of organic fertilizers. They include minerals and other materials that come directly from the earth, and are components in many blended organic fertilizers (Figure 1). Many commercial products in this category are widely marketed as organic fertilizers because they are not chemically synthesized. Like all types of mining, however, obtaining these fertilizers is an extractive process and unsustainable in the long term. The use of natural mineral fertilizers is restricted in some types of organic farming, and the Organic Materials Review Institute rejects their use for certified organic food production (OMRI 2011). Other countries and some states, however, have their own organic certification process and permit the use of natural mineral fertilizers.

### Guano

Guano is the accumulated excrement of seabirds or bats. It has been used as a fertilizer for hundreds of years since the Incas collected it along the coast of Peru. It is an excellent fertilizer due to high levels of phosphorus and nitrogen, and does not have any noticeable odor. Because rainwater leaches soluble nitrogen out of guano, the best guano deposits are found in very dry climates; desert coastal areas or islands are ideal guano collection sites. Large populations of seabirds use these locations as their land base for resting and breeding. After many centuries, guano deposits can exceed several meters in depth. Before the development of synthetic fertilizers, guano was one of the primary sources of fertilizer, and wars have even been fought to control the supply (Wikipedia 2011a). One of the largest mining operations occurred on the small South Pacific island of Nauru where centuries of deposition by seabirds created vast reserves of guano. Although very profitable, the



**Figure 1.** The terminology of organic fertilizers is complicated, and the various types can best be illustrated with a flow chart.

mining operation had a relatively short lifespan that had severe economic consequences on the local population (US CIA 2011).

### Rock Phosphate

Natural deposits of fluoroapatite are the raw material of most phosphate fertilizers. Deposits are currently mined in North Africa, the former Soviet Union, and in Florida, Idaho, Montana, Utah, and Tennessee. The raw ore contains 14% to 35% phosphate ( $P_2O_5$ ), and is processed by grinding and washing into a fine granular fertilizer. Rock phosphate is very insoluble in water, and is not used in soluble formulations; it does make an effective slow-release granular fertilizer (California Plant Health Association 2002). Because of its low solubility, rock phosphate has been recommended as an ideal phosphorus fertilizer to encourage the development of mycorrhizal fungi (Amaranthus 2011).

### Sodium Nitrate

Sodium nitrate ( $NaNO_3$ ) is commonly known as Chilean or Peruvian saltpeter due to the large caliche mineral deposits found in both countries. It was first introduced as a fertilizer in Europe in the early 1800s, although its primary use was for munitions. Later that century, sodium nitrate became so valuable that a war was waged between Chile, Peru, and Bolivia to control the most valuable deposits (Wikipedia 2011b). In the early 1900s, sodium nitrate was one of the few mineral fertilizers mentioned for forest nursery crops (Tillotson 1917). Although this fertilizer has been used in organic farming for many years, several organic certifying agencies have concluded that mined mineral fertilizers conflict with basic organic principles. For example, the USDA National Organic Program currently restricts use of sodium nitrate to less than 20% of total annual applied nitrogen and requires that growers phase out its use over time (Gaskell and Smith 2007).

### Magnesium Sulfate

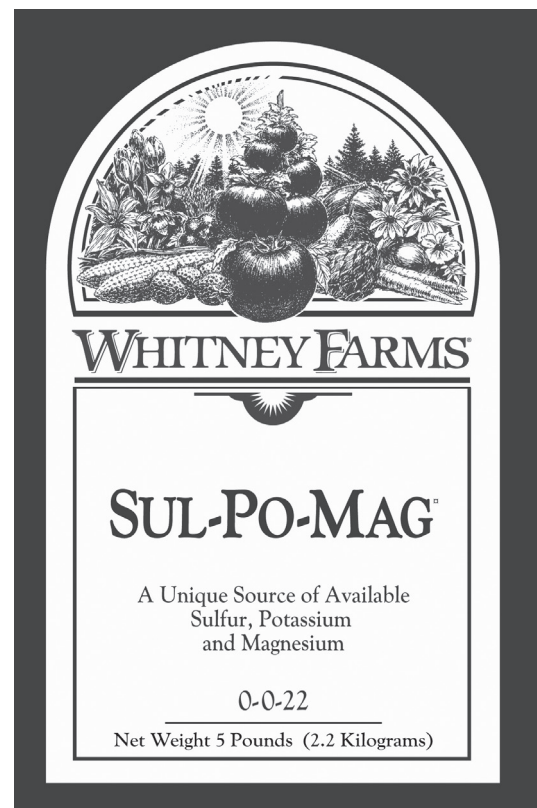
Magnesium sulfate ( $MgSO_4$ ) is better known as Epsom salts or Kieserite. Although more widely used for medicinal purposes, magnesium sulfate is a very soluble source of the secondary macronutrients magnesium and sulfur, and has been used in the formulation of liquid fertilizers for container tree nursery crops (Landis and others 1989).

### Sul-Po-Mag

Technically known as sulfate of potash-magnesia or langbeinite (Figure 2A), Sul-Po-Mag is mined from marine evaporite deposits (California Plant Health Association 2002). It was originally discovered in Germany and contains soluble nutrients in the following ratio: 22% potassium, 22% sulfur, and 11% magnesium (Figure 2B). K-Mag Natural is a common trade name; this product is ideal for supplying potassium and sulfur without any accompanying nitrogen. Sul-Po-Mag is a common component in many blended organic fertilizers.

### Blended Organics

Blended organics are the newest category of organic fertilizers; products contain a mixture of processed organic plant or animal wastes supplemented with natural minerals (Figure 1). Blended organics aren't discussed in any fertilizer publication that we could find, so we created this category. It is easy to identify blended organic fertilizers by checking the ingredients on their labels, and a wide variety of products can be found on the internet. Many horticultural suppliers, such as Black Gold® (Bellvue, WA), are entering the organic fertilizer market. For example, they offer an all-purpose organic fertilizer (5N:5P<sub>2</sub>O<sub>5</sub>:5K<sub>2</sub>O) that contains processed organics, including bone and



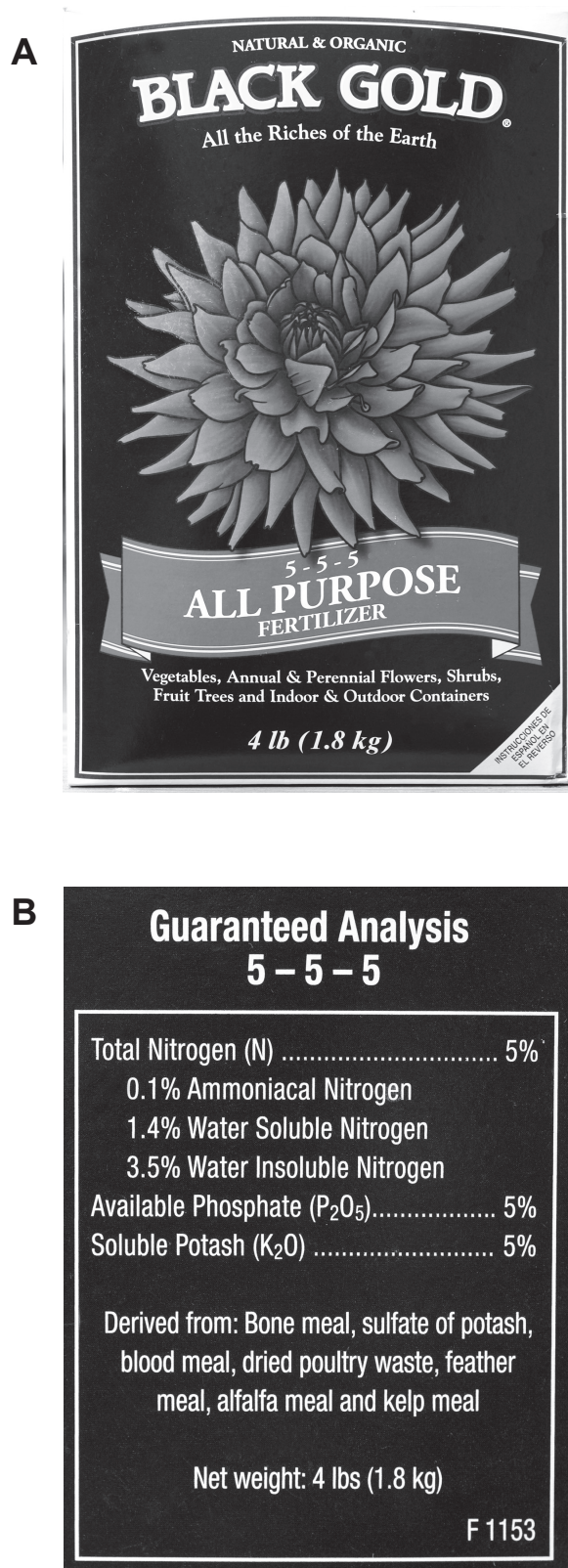
**Figure 2.** Mineral fertilizers, such as Sul-Po-Mag, are mined from the earth and are considered organics because they are naturally occurring and not synthesized by humans.

blood meal, blended with the natural mineral potassium sulfate (Figure 3A). If you want an organic fertilizer that is made from sustainable materials, that is not mined or synthetically made, be aware that many blended organic fertilizers contain natural minerals (Figure 3B).

## Organic Fertilizer Forms

### Solid Organic Fertilizers

Powdered or granular fertilizers can be derived from unprocessed organics, processed organics, natural minerals, or blended organics (Figure 1). Solid organic fertilizers have not been widely used in forest or native plant nurseries, or their use has not been documented in the published literature. Milorganite® (Milwaukee,



**Figure 3.** Blended organic fertilizers (A) contain processed organics and natural minerals, such as sulfate of potash (B).

WI) is one example that is produced from processed sewage sludge. This granular fertilizer was used in several USDA Forest Service nurseries with good success, and Dutton (1977) documented the pros and cons of using Milorganite® at USDA Forest Service Wind River Nursery (Carson, WA). Biosol® (6N:1P<sub>2</sub>O<sub>5</sub>:3K<sub>2</sub>O), another solid organic fertilizer, was developed from the fermentation of soybean and cottonseed meal, and is a by-product of the pharmaceutical manufacture of penicillin. Biosol® is supplemented with Sul-Po-Mag to balance the nutrient content. Although it has never been used in forest or native plant nurseries to our knowledge, Biosol® has been successfully used as a fertilizer in native plant restoration projects (Claassen and Carey 2007; Steinfeld and others 2007).

### Liquid Organic Fertilizers

Liquid organic fertilizers can be derived from processed organics, natural minerals, or blended organics (Figure 1). Again, most of these products are so new that they are not discussed in traditional fertilizer texts, and the best and most current information on liquid organic fertilizers can be found on-line. GrowOrganic (Grass Valley, CA: URL: <http://www.groworganic.com/>) lists liquid organic fertilizers that are developed from a variety of sources, including processed fish waste, soybean meal, kelp, and even recycled foodstuffs. Many products are targeted to specific crops, but others are for more general use. For example, Earth Juice Grow (2N:1P<sub>2</sub>O<sub>5</sub>:1K<sub>2</sub>O) is derived from bat guano, kelp, sulfate of potash, feather meal, oat bran, blood meal, and steamed bone meal. Liquid organic fertilizers can present some operational difficulties. In a review article on the production of organic vegetable crops, Gaskell and Smith (2007) conclude that liquid organic fertilizers lack uniformity because they are subject to settling and microbial breakdown. In addition, many liquid organic fertilizers include organic material in suspension and must be filtered or continually agitated during fertigation to prevent the material from plugging nozzles.

Very little formal research has been published on growing forest or native plant crops with liquid organic fertilizer. Unfortunately, most published research was not properly designed, so the results are confounded, making them difficult to properly interpret. In one study, Norway spruce (*Picea abies* [L.] Karst.) seedlings were grown in either 100% Sphagnum peat moss or peat moss amended with forest organic matter, including pine bark. They were grown for 2 years in a nursery with either conventional synthetic fertilizers or a liquid organic fertilizer made from composted chicken manure. The seedlings grown with synthetic fertilizer were significantly taller at the end of nursery culture but, after 3 years in the field, the organically grown seedlings had faster growth rates (Vaario and others 2009).

### Comparison of Organic versus Synthetic Fertilizers

Because of the variability involved, it is difficult to compare organic and synthetic fertilizers. Some generalizations, however, can be made (Table 1).

#### Mineral Nutrient Analysis

By law, all fertilizers must list their chemical analysis (%N: %P<sub>2</sub>O<sub>5</sub>:%K<sub>2</sub>O) on the label. Almost all organic fertilizers have relatively low analyses. The nitrogen percentage is rarely above 15%, and more typically in the range of 5% to 10% (Figure 4). Higher analysis products are usually supplemented with natural minerals, such as sodium nitrate.



**Table 1.** Comparison of attributes of organic and synthetic fertilizers.

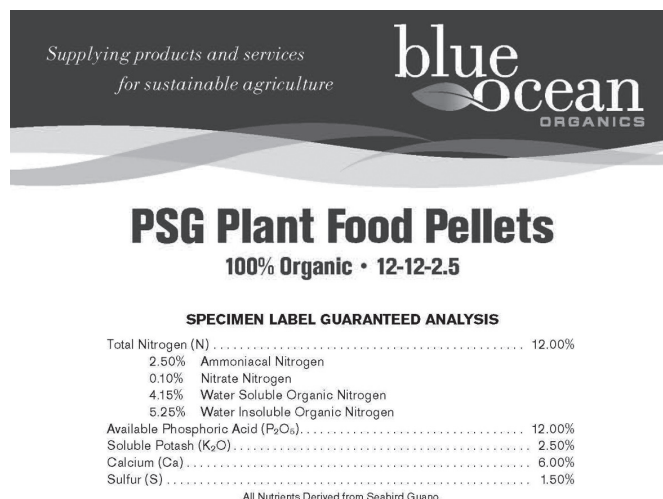
Factor	Organic	Synthetic
Mineral Nutrient Analysis	Low	High
Range of Mineral Nutrients	All	One to Many
Nutrient Release Rate	Slower	Faster
Nutrient Uptake	Slower	Faster
Compatibility with Beneficial Microorganisms	Yes	At Low Levels
Cost	More	Less
Handling	Bulkier	More Concentrated
Ecological Sustainability	Yes	No
Water Pollution Risk	Low	High
Other Benefits	Improves Soil Texture; Encourages Soil Microbes	Better for Research

## Range of Mineral Nutrients

One major benefit of organic fertilizers is that they contain a full complement of all 13 mineral nutrients. Some synthetic fertilizers, on the other hand, contain one or only a few mineral nutrients. Some of the newest synthetic fertilizers have been specially formulated to contain the full range of mineral nutrients.

## Nutrient Release Rate

One of the major differences between organic and synthetic fertilizers is how fast their nutrients become available to plants. The first step in mineral nutrient uptake is dissolution in water, and this process is much easier and faster for synthetic fertilizers. Synthetic fertilizers are formulated as salts that are very soluble. Unprocessed organic fertilizers, such as manure, must first be broken down into smaller particles by soil microorganisms and then converted to a soluble form. Even processed organics contain a large percentage of insoluble nitrogen that must undergo microbial decomposition before being available for plant uptake (Figure 4). Liquid organic fertilizers have the benefit of



**Figure 4.** Organic fertilizers have relatively low nutrient analysis compared to synthetic fertilizers, and much of the nitrogen is insoluble.

being already in solution, or at least in aqueous suspension.

A recent research trial provides a good illustration of the differences in nutrient release rates among a variety of organic and synthetic fertilizers. Claassen and Carey (2007) found that nearly all (95%) of the nitrogen in synthetically produced ammonium phosphate was released within a few days of application; two formulations of synthetically produced controlled-release fertilizers took about 150 days to release 95% of their nitrogen. In contrast, the nitrogen release of two types of organic fertilizers was much slower. Commercially processed organic wastes released from 20% to 60% of their nitrogen after 200 days; municipal composts released only about 10% of their initial nitrogen in the same period.

## Nutrient Uptake

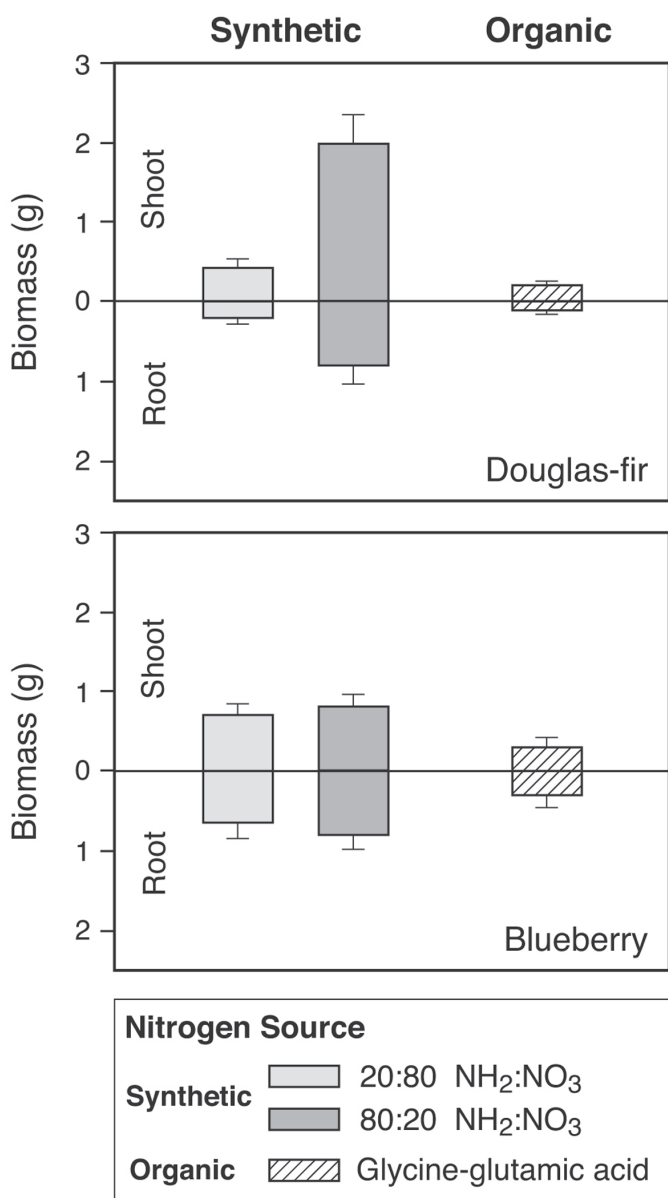
Most plant nutrients enter plants as electrically charged ions from the soil solution. Nutritional research has established that organic nitrogen molecules can be taken up by nursery plants directly as amino acids. For example, the growth of Scots pine (*Pinus sylvestris*) seedlings was similar whether they were fertilized with inorganic nitrogen or supplied with amino acids (Ohlund and Nasholm 2001). Metcalfe and others (2011) found that, although seedlings of two conifers, Sitka spruce (*Picea sitchensis*) and Douglas-fir (*Pseudotsuga menziesii*), and two shrubs, oval-leaf blueberry (*Vaccinium ovalifolium*) and salmonberry (*Rubus spectabilis*), readily took up nitrogen as organic amino acids, all four species grew significantly larger when grown with ammonium and nitrate fertilizers (Figure 5). This finding is supported by a recent, comprehensive literature review that concludes organic nitrogen can be taken up by plants, but direct evidence that this constitutes significantly to plant nutrition is lacking. Nursery trials comparing synthetic and organic fertilizers are very difficult to design; organic fertilizers contain numerous nutrients so it is impossible to isolate the effects of just one nutrient.

## Compatibility with Beneficial Microorganisms

Perhaps one of the most underappreciated benefits of organic fertilizers is that they promote the growth of beneficial soil microorganisms, including mycorrhizal fungi and nitrogen-fixing bacteria. Much research has shown that high levels of synthetic fertilizers, especially nitrogen and phosphorus, inhibit the establishment and development of mycorrhizal fungi. This is particularly evident in the soilless growing media of container seedlings where applications of high levels of soluble, synthetic fertilizers are common (Castellano and Molina 1989). Conversely, beneficial microorganisms are favored by organic fertilizers because nutrients are released at a slower rate and the organic component improves soil conditions. A recent survey of ectomycorrhizal fungal species in Polish bareroot nurseries found that ascomycetes were more common when compost was used as fertilizer (Trocha and others 2006).

## Cost

Organic fertilizers are typically several times more expensive per nutrient compared to synthetic products. For example, the cost per unit of nitrogen, as urea or ammonium nitrate, for organic fertilizers was higher than that of synthetic nitrogen fertilizers (Gaskell and Smith 2007). A mathematical comparison of fertilizer costs is difficult because each contains different percentages of nutrients and values must be expressed on a per weight or per volume basis. Although they are more expensive strictly on a per nutrient basis, both processed and unprocessed organic fertilizers provide many other benefits that are hard to evaluate, including adding organic matter and stimulating



**Figure 5.** Douglas-fir (*Pseudotsuga menziesii*) and oval-leaf blueberry (*Vaccinium ovalifolium*) seedlings grown with two different synthetic nitrogen fertilizers were significantly larger than those grown with organic nitrogen (Metcalfe and others 2011).

soil microorganisms (Table 1). Synthetic fertilizers also have hidden costs, such as carbon emissions during their manufacture and the ecological impacts of increased potential for water pollution. In the final analysis, because fertilizers represent only a very small percentage of the cost of producing nursery stock, price may not be a deciding factor on whether to use organic fertilizers.

### Handling and Application

Because of their bulkiness and low nutrient analysis, unprocessed organics are more expensive to ship, store, and apply compared with high analysis synthetic fertilizers. This is particularly true of manure and other plant and animal wastes. Conversely, synthetic fertilizers are more uniform in quality, have a high nutrient analysis per unit

weight, and are much easier to apply to crops. This is particularly true for container nurseries, because no good method yet exists for applying unprocessed organics to container nursery crops.

### Ecological Sustainability and Water Pollution

One of the real benefits of organic fertilizers is that they are kind to the environment and many can be obtained from recycled materials, for example, compost and municipal sludge. Not only can nurseries recycle cull seedlings, weeds, and other organic materials through composting, but they can serve as places for municipalities to recycle leaves, yard clippings, and other such wastes that would otherwise go to landfills (Morgenson 1994). Because nursery crops are not consumables, sewage sludge and even some industrial wastes can be used as fertilizers. Nurseries can generate cooperative agreements with municipalities or industries to reduce their composting costs while generating an environmentally beneficial source of plant nutrients (Rose and others 1995).

Nutrients in organic fertilizers are much less susceptible to leaching than those in synthetic fertilizers. Although this doesn't apply to natural minerals, both processed and unprocessed organic fertilizers release their nutrients slowly and in a form that remains in the soil profile. Synthetic fertilizers often release their nutrients much faster than plants can use them, with the excess nutrients potentially entering surface or ground water, resulting in pollution. This is especially serious with fertilizers containing the anions nitrate and phosphate that are not adsorbed on the cation exchange sites and therefore easily leached (Landis and others 1992). Although sewage sludge is one organic fertilizer that can cause water pollution when applied improperly, guidelines for proper application in bareroot forest nurseries have been developed (Rose and others 1995).

### Applications in Forest and Native Plant Nurseries

Growers need to have ethical or ecological reasons for wanting to use organic fertilizers because quality crops of forest trees and other native plants have been grown for half a century using only synthetic fertilizers. Although the higher cost of organics is often given as a reason to use synthetics, fertilizers are a small portion of total production costs and organic fertilizers have many other benefits.

As previously mentioned, it is difficult to make direct comparisons between organic and synthetic fertilizers in nursery trials. Of all the various methods used to evaluate the effects of fertilizers, plant growth rates and quality are the true tests. With the increased interest in organic farming, numerous examples exist showing that organic fertilizers can be used effectively. The benefit of synthetic fertilizers to the growth of forest tree seedlings has been well established, but it would be interesting to see direct comparisons of the growth rate between crops grown with organic and synthetic fertilizers applied at the same nitrogen rate.

### Using Organic Fertilizers in Bareroot Nurseries

Because plants are grown in large volumes of field soil, bareroot nurseries have the greatest potential for using all types of organic fertilizers. In particular, unprocessed materials like manure and sewage sludge can provide a base level of mineral nutrients and a source of valuable organic matter to maintain soil tilth. Bulk organics should be applied as soon after crops are harvested to allow

time for decomposition. Application rates vary between the different materials and should be determined by operation trials because of differences in soil type and nursery climate; specific rates for Milorganite® and sewage and fish sludge have been reported for forest nurseries (Dutton 1977; Rose and others 1995). Because of the slow release rates of most organic fertilizers, it may be prudent to use organic fertilizer to provide a base level of nutrients and synthetic fertilizer to respond to crop growth and development during the season.

## Using Organic Fertilizers in Container Nurseries

Because container plants are typically grown in artificial growing media, it would be difficult to incorporate either processed or unprocessed organic fertilizers, particularly in smaller volume containers. Organic fertilizer could be used in containers larger than 1 l (60 in<sup>3</sup>). Composts could be incorporated into growing media, but they must be fully mature to prevent fertilizer burn from excess ammonia. Fertigation is the preferred fertilization method in many forest and native plant container nurseries, and growers could incorporate the more soluble natural mineral organics into their mixes. One of the challenges of completely converting to organic fertilizers is how to achieve the high soluble nitrogen levels that are used to promote the rapid growth rates in greenhouse crops. Although the number of highly soluble organic fertilizers is very limited, sodium nitrate could be used to provide nitrogen, and Sul-Po-Mag and Epsom salts could provide other macronutrients. Many newer blended organic fertilizers contain a full complement of macro- and micronutrients. In a recent trial with a grass test crop, 3 brands of liquid organic fertilizers produced growth similar to conventional synthetic fertilizers. The authors concluded that the nitrogen availability of the synthetics was much faster than the organic fertilizers and that the organic solutions should be filtered before their use in fertigation systems (Hartz and others 2010).

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# Applications of Hydrogels in the Nursery and During Outplanting

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Landis TC, Haase DL. 2012. Applications of hydrogels in the nursery and during outplanting. In: Haase DL, Pinto JR, Riley LE, technical coordinators. National Proceedings: Forest and Conservation Nursery Associations—2011. Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. Proceedings RMRS-P-68. 53-58. Available at: [http://www.fs.fed.us/rm/pubs/rmrs\\_p068.html](http://www.fs.fed.us/rm/pubs/rmrs_p068.html)

**Abstract:** Hydrogels have a variety of potential uses including application to plants in the nursery and at the time of outplanting. Absorptive capacity of these gels is influenced by their chemical and physical composition as well as the ion concentration of the liquid being absorbed. The most common uses for hydrogels in nurseries or during outplanting are incorporation or root dips. Research results are mixed regarding hydrogel influences on plant water uptake and vary by product and environmental conditions. It is recommended that growers or planters conduct small trials to determine whether there are benefits to using hydrogels under their specific conditions.

**Keywords:** Polymer gels, plant moisture stress, root dips

## What are Hydrogels?

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Hydrophilic gels, or “hydrogels”, which are commonly known as superabsorbents, are crosslinked polymers that can absorb 400 to 1500 times their dry weight in water (Figure 1A). Most of the early hydrophilic polymers were destined for non-agricultural uses, most notably baby diapers, but have also found uses in such diverse applications as oil recovery, food processing, water purification, and wound dressings (Peterson 2002).

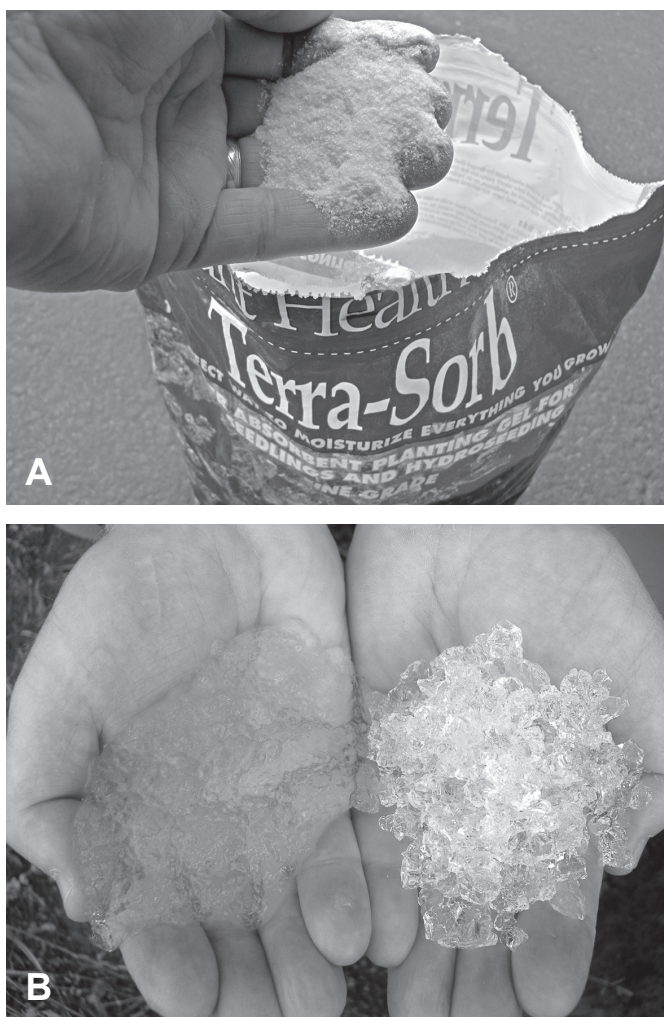
Hydrophilic polymers can be categorized into three classes, but can be chemically manipulated to produce products with different characteristics in each class (Mikkelsen 1994):

1. Naturally occurring polymers are starch-based polysaccharides that are made from grain crops such as corn and wheat. Natural polymers are most commonly used in the food industry as thickening agents.
2. Semi-synthetic polymers are derived from cellulose, which is chemically combined with petrochemicals. One of the first hydrogels specifically designed for horticulture was a polyethylene polymer combined with sawdust (Erazo 1987).
3. Synthetic polymers are made from petrochemicals and polyacrylamides (PAMs) are one of the most popular polymers that are chemically linked to prevent them from dissolving in solution. Linear chain polyacrylamides are used for erosion control, canal sealing, and water clarification whereas crosslinked polyacrylamide hydrogels are most commonly used in horticulture (Peterson 2002).

## Factors Affecting Efficacy of Hydrogels

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The absorptive capability of hydrogels is affected by their physical and chemical composition as well as environmental factors, such as the dissolved salts in the surrounding water solution.



**Figure 1.** Hydrophilic gels, commonly known as hydrogels, are dry crystals that can absorb many times their own weight in water (A), and commercial products vary in chemical composition and particle size (B). [A, courtesy of David Steinfeld; B, courtesy of Diane Haase].

### Chemical and physical composition

A web search will yield some information about the chemical composition of the various products, and most are either inorganic polymers or PAMs. The exact chemical composition of hydrogel products are trade secrets and many are simply described as “polymers” or “polyacrylamide”. Most are inorganically based but Zeba<sup>®</sup> is unique because it is starch-based (Table 1). Some hydrogel products also contain spores of mycorrhizal fungi, biostimulants, or slow release fertilizer.

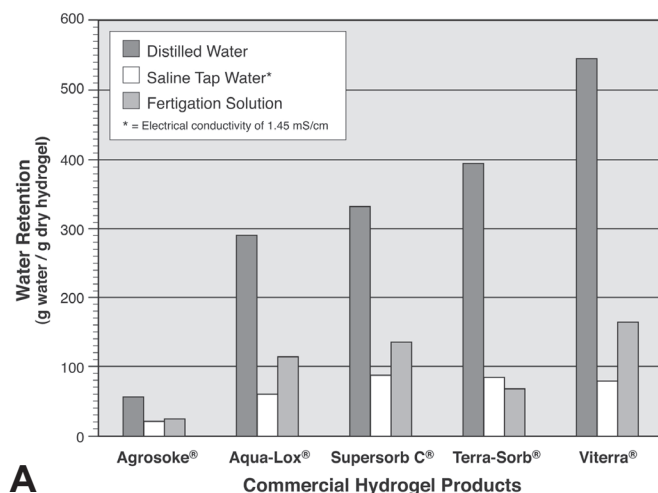
**Table 1.** Chemical composition of typical hydrogels used in horticulture or restoration.

Brand Name	Chemical Class	Other Additives
Boiler 1-2-3 <sup>®</sup>	Inorganic Polymer	Mycorrhizal spores and biostimulant
Bio-Organics <sup>®</sup>	Inorganic Polymer	Mycorrhizal spores
Soil Moist <sup>®</sup>	Polyacrylamide	Some contain mycorrhizal spores, and one contains slow-release fertilizer
Stockosorb <sup>®</sup>	Polyacrylamide	None
Viterra <sup>®</sup>	Inorganic Polymer	None
Zeba <sup>®</sup>	Starch polymer	None

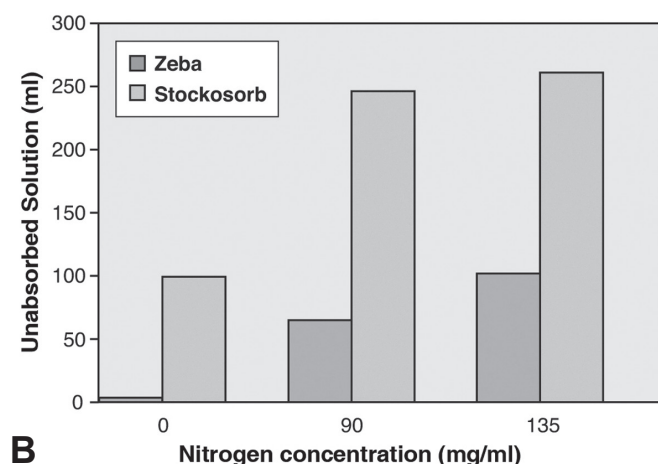
Physically, the particle size of the various hydrogel products can vary considerably and this attribute has a significant effect on how they are best used. Fine-textured products are best for root dips, whereas coarser grades are better for soil incorporation (Figure 1B). Soil Moist<sup>®</sup> is available in several different formulations for specific applications, including soil incorporation, root dips, hydroseeding, seed coatings, or even to retain moisture in cut Christmas trees (JRM Chemical Inc).

### Dissolved Salts

Mikkelsen (1994) states that divalent ions, such as calcium (Ca<sup>++</sup>) and magnesium (Mg<sup>++</sup>), are more restrictive than monovalent ions, such as ammonium nitrogen (NH<sub>4</sub><sup>+</sup>) and potassium (K<sup>+</sup>). One research trial (Wang and Gregg 1990) soaked commercially available hydrogels with several different solutions including distilled water, moderately saline tap water (electrical conductivity of 1.45 mS/cm), and a dilute fertilizer solution. After soaking, the saturated hydrogels were allowed to drain to determine their absorptive capacity. The optimal absorption is reflected by the weight of water retained in the distilled water treatment, in which the hydrogels varied considerably (Figure 2A). Agrosoke absorbed and retained considerably less water than the other hydrogels, with Viterra retaining the most. The effect of dissolved salts of the amount of water that can be absorbed



**A**



**B**

**Figure 2.** The amount of water that can be retained depends on the hydrogel’s chemical composition and environmental factors like the salts dissolved in the surrounding solution (A). Increasing levels of fertilizer can reduce the amount of water absorbed by hydrogels (B). [A, modified from Wang and Gregg (1990), B, modified from NTC (2007a)].

by the various products can be seen in the other two treatments: the saline tap water and the fertigation solution. The tap water reduced the water retention of the commercial hydrogel products substantially, from a 65% decrease in Agrosoke to almost 85% in Viterra. Because it contained a variety of fertilizer ions, the water retention for dilute fertilizer treatment was different again (Wang and Gregg 1990). In a similar study, 2.5 g of hydrogel was added to 450-ml replications of water containing 0, 90, or 135 mg N/ml. After 40 hours, the amount of unabsorbed solution was measured and was significantly higher with increasing amounts of nitrogen (NTC 2007a)(Figure 2B). The bottom line is that the laboratory absorption values using distilled water are significantly different than the amount of water that can be absorbed and retained in the nursery or on the outplanting site.

## Application of Hydrogels in Nurseries, Reforestation, and Restoration

Exactly how hydrogels benefit plants depends on how they are applied, and the most common used in nurseries or during outplanting are incorporation or root dips. The main use of hydrogels has been to retain water for plant growth especially when irrigation isn't provided, but new uses are continually being discovered.

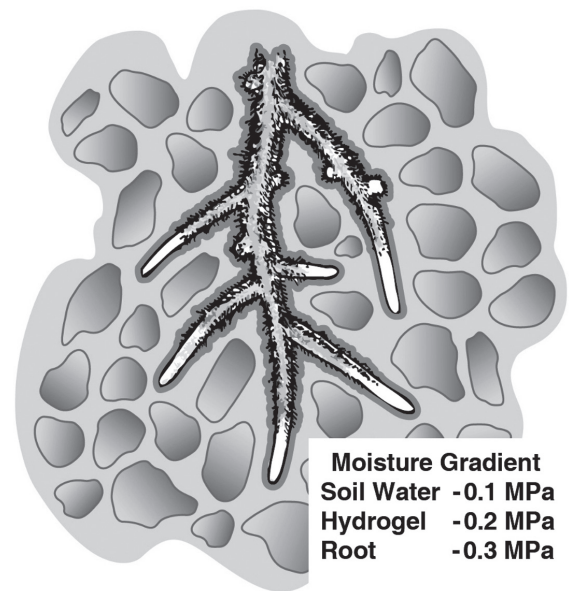
### Gel seeding

This was one of the first applications of hydrogels in horticulture and involves sowing seeds mixed into a hydrogel. The objective is that the hydrogel will retain moisture around the germinating seeds and improve establishment either in a nursery or on an outplanting site. Research trials coating leguminous tree seeds with hydrogels before sowing in a greenhouse or in field soil showed mixed results between plant species; larger-seeded species survived and grew better. One hypothesis was that coating seeds with hydrogels may reduce germination and emergence by reducing aeration around the seeds (Henderson and Hensley 1987). In a more recent test, hydrogels were applied to seeds of Scotch pine (*Pinus sylvestris* L.) and Austrian pine (*Pinus nigra* L.) prior to germination tests in the laboratory, a greenhouse, and a bareroot nursery. The hydrogel treatment reduced germination percentage for both species in the laboratory but Scotch pine treated with hydrogel germinated better than the controls in the greenhouse. In spite of these germination problems, the authors considered that the improved seedling growth after 2 years in the bareroot nursery justified the use of hydrogels in future trials (Sijacic-Nikolic and others 2010). The paucity of other published trials in recent years suggests that gel seeding has little application in forest and native plant nurseries or for direct seeding on project sites.

### Root dips

When applied as a root dip, hydrogels coat fine roots and protect them against desiccation. One potential benefit is that hydrogel dips may function similarly to the natural polymeric mucilages produced by healthy roots. One recent study demonstrated that mucilage weakens the drop in water potential at the rootsoil interface, increasing the conductivity of the flow path across soil and roots and reducing the energy needed to take up water (Carminati and Moradi 2010). Hydrogel root dips could provide the same function, improving root-to-soil contact (Thomas 2008), and filling-in air spaces around transplants or outplanted seedlings (Figure 3).

The concept of dipping plant roots before transplanting or outplanting has been around for many years because it is intuitively attractive. Roots of nursery plants can dry as they are exposed to the atmosphere



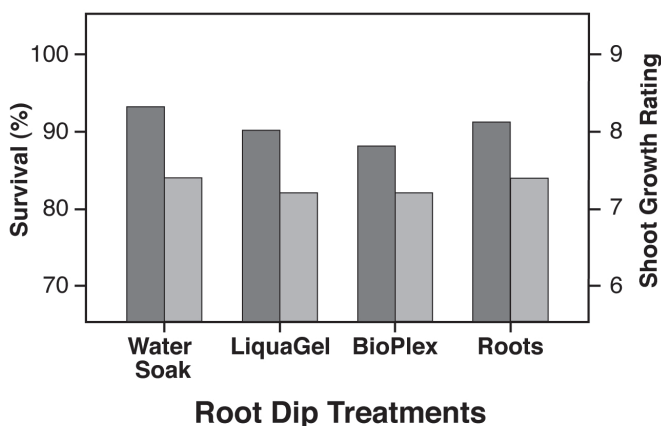
**Figure 3.** When hydrogels are applied as root dips, they function like the mucilage naturally produced by healthy roots and improve water uptake by increasing root-to-soil contact and filling-in air spaces.

during harvesting and handling and so it makes sense to apply a coating to protect them (Chavasse 1981). Southern nurseries have been dipping the roots of their bareroot stock in a clay slurry for decades, but many have switched to hydrogels in recent years (e.g. Bryan 1988). In the western states, the use of root dips is less common but some forestry organizations sell protective root dips as part of their tree distribution programs (for example, Kansas State Forest Service 2010). For a comparison of the various root dip products and their effectiveness, see Landis 2006.

In a comprehensive literature review of root dips, Sloan (1994) concluded that they were detrimental to bareroot stock when applied before storage. After outplanting, most of the research at that time showed that hydrogel root dips do not increase survival or growth under very dry conditions and are merely an added expense. One important conclusion is that, while root dips can be beneficial in protecting seedlings from exposure to sun and wind, tree planters should not assume that root dipping will restore seedling vigor after improper handling.

Another limitation of comparison trials of root dips is that all too often no appropriate control was included. Many dips were compared against no root dip at all but, since all hydrogels are applied in a water slurry, it makes sense to use a water dip as a control. One recent research study did just that, and tested 3 hydrogel-based root dips against a water dip control (Bates and others 2004). The seedlings of four bareroot conifers were dipped into one of 3 commercial root dips or a water control. When evaluated for survival, none of the products showed a significant improvement over the water dip; likewise, the commercial root dips gave no appreciable shoot growth benefit after 2 years (Figure 4). In another study, Douglas-fir seedlings (*Pseudotsuga menziesii* Mirb. Franco) were treated with a water dip and three hydrogel treatments varying rates of soluble fertilizer. After one growing season, there were no differences among treatments for xylem water potential, height growth, stem diameter growth, or survival (NTC 2007b).

The vast majority of research has been with bareroot conifer seedlings at the time of outplanting. We only found one published article on dipping the roots of container plants in hydrogel prior to outplanting. When two species of Eucalyptus container seedlings had their



**Figure 4.** Compared to a water soak, none of three hydrogel root dips improved survival or shoot growth of conifer seedlings two years after outplanting (Bates and others 2004).

root plugs dipped in a hydrogel slurry, mortality at 5 months after outplanting was more than cut in half (Thomas 2008). Likewise, only one study looked at the effects of hydrogel dips on bareroot hardwood seedlings. When the roots of red oak (*Quercus rubra* L.) seedlings were dipped into a hydrogel slurry, and then subjected to drought stress, the hydrogel-treated seedlings had greater root moisture content and less root membrane leakage than plants without root dipping. These differences were not reflected in increased growth, however (Apostol and others 2009). Both of these studies stress the importance of using fine grade hydrogel when root dipping; using hydrogel with dry particle sizes from 0.2 to 0.3 mm covered roots much better than larger grades which clumped and fell off the roots (Sarvas 2003). Terra-Sorb® is available in three particle diameters: coarse (2 to 4 mm), medium (0.75 to 2 mm), and fine (0.10 to 0.75 mm), with the fine grade recommended for root dipping (Plant Health Care 2010). We only found one article on the use of hydrogel dips before transplanting in a bareroot nursery: dipping bareroot Norway spruce (*Picea abies* L.) seedlings prior to mechanical transplanting increased shoot height and root collar diameter compared to the controls (Sarvas 2003).

## Amendment to container growing media

Another application which has been widely tested is the incorporation of hydrogels into growing media prior to sowing as a means to hold more water and reduce moisture stress. In addition to increasing water holding capacity, hydrogels have been shown to retain nutrient ions against leaching especially in growing media with low cation exchange capacities. One trial found this to be true for the cations ammonium and potassium, but not for the anionic nitrate which is one of the major causes of nutrient runoff from nurseries (Henderson and Hensley 1985).

Many earlier studies showed that, while hydrogels definitely increased the water holding capacity of the growing medium, this was not always reflected in increased plant growth. Douglas-fir container seedlings grown in hydrogel-amended medium averaged lower moisture stress than those in the unamended control media when subjected to desiccation following lifting. However, no differences were found among treatments for height, stem diameter, root volume, and shoot volume (NTC 2009). When European birch seedlings were grown in a hydrogel-amended medium, subsequent growth was actually reduced compared to the control seedlings (Tripepi and others 1991). The authors suggest that the reduced growth could be a result of reduced aeration resulting from less macropore space in the gel-amended



**Figure 5.** Many brands of growing media for the home gardener contain hydrogels.

media. This observation was supported by reduced root mass in the seedlings from the gel treatment. Another study found that air space in pine bark and pine bark/sand media was reduced in the hydrogel-amended growing media (Fonteno and Bilderback 1993).

In operational practice, few nurseries use a growing medium amended with hydrogels, although many such products are available for the non-professional or home gardener (Figure 5). Good growers want complete control of the water-holding capacity of their growing media, which would be lost with hydrogel amendments. Also, the swelling hydrogel particles must expand somewhere after hydration and undoubtedly reduce the amount of macropores which are so essential for good drainage and air exchange.

## Soil amendment in bareroot nursery beds

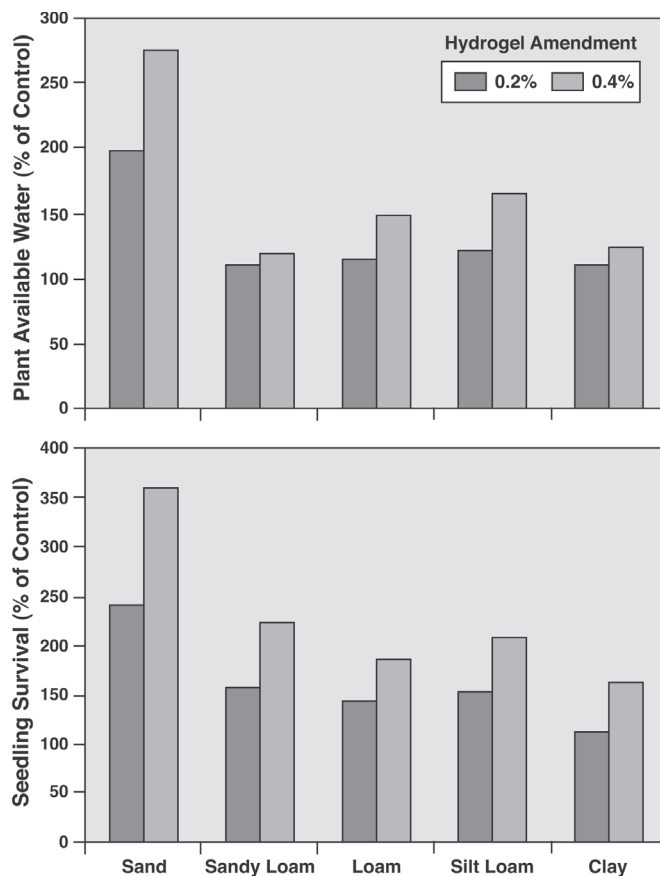
Amending bareroot nursery soil to retain moisture may have some benefit, especially in areas of the nursery where variations in exposure, soil texture, or drainage patterns leave particular beds vulnerable to desiccation stress. Douglas-fir seedlings were transplanted into beds amended with three rates of hydrogel or a non-amended control treatment. Seedlings were measured periodically for xylem water potential just prior to irrigation. Stress levels were relatively low during the summer when the trial was conducted but one measurement date indicated that control seedlings had higher moisture stress levels compared to those grown in soil amended with hydrogel. At the time of lifting, no differences in seedling growth were found among treatments (NTC 2009).



## Soil amendment during outplanting

The final application for hydrogel is to amend soils on the outplanting site, especially on droughty or severely-disturbed sites with the objective of retaining water that would normally be lost to evaporation or leaching. They have also been shown to retain nutrient ions that could be leached out of the root zone (Mikkelsen 1994). The method of application is important and incorporating hydrogels in the rooting zone is much more effective than applying in a band or layer (Kjelgren and others 1994). When 8 grams of hydrogel was applied per kilogram of three different soil textures, the available water content increased 1.8 times that of the unamended control for the clay, 2.2 times for the loam, and 3.2 times for the sandy loam soil (Abedi-Koupai and others 2008). In another study, two rates of hydrogel were added to 5 different soil textures ranging from sand to clay and then seedlings of nine different tree species were planted in pots with both treatments and a control (Agaba and others 2010). The plants were subjected to moisture stress treatments in a greenhouse until some seedling mortality occurred. The percentage of plant available water increased from around 100% in the clay to almost 300% in the sandy soil, and these results were mirrored very closely by the survival of the tree seedlings (Figure 6).

Hydrogel amendments are considered most effective on sandy soils and in droughty environments. When a sandy soil was amended with a range of hydrogel treatments and planted with *Pinus halepensis* Mill. seedlings, the water retention of the soil increased exponentially with increasing additions of hydrogel. When the seedlings were subjected to controlled desiccation, the seedlings in soils with the highest amount of hydrogel survived twice as long as those in the con-



**Figure 6.** Hydrogel amendments incorporated into a range of soil textures significantly increased plant available water and seedling survival compared to the controls (modified from Agaba and other 2010).

trol soils. Water potential measurements showed that seedlings in the amended soils had considerably less moisture stress than the controls. Shoot growth and root growth were also significantly increased with the hydrogel amendment (Huttermann and others 1999). Conversely, Sarvas and others (2007) reported a 21% reduction in survival of Scots pine (*Pinus sylvestris* L.) as compared with the controls when polyacrylamide gel was placed in the planting hole. Similarly, a recent study showed that the use of hydrogels did not increase

loblolly pine (*Pinus taeda* L.) seedling survival and, in some cases, decreased survival (Starkey and others 2012). The authors concluded that the efficacy of hydrogels to increase seedling survival after outplanting is dependent upon the particle size and availability of soil moisture and recommended its use primarily as a root dip to protect roots from desiccation during the planting process.

One of the things almost never presented in research studies is cost of the hydrogel treatment. The only reference we found was for Eucalyptus seedlings where the hydrogel amendments to a sandy soil increased survival by a factor of 3 at a cost per plant of 17 to 27% (Callaghan and others 1989).

## Summary

Hydrophilic polymers have been used in agriculture for over 40 years, and a variety of products are available for a wide range of uses both in the nursery and on the outplanting site. When incorporated into growing media or soil either at the nursery or on the outplanting site, hydrogels absorb and retain water that would normally be lost to evaporation or leaching. Hydrogels have also been shown to retain cationic nutrients against leaching. When applied as a root dip, hydrogels can protect roots against desiccation and increase the root-to-soil contact after outplanting. Results of nursery and field trials have been mixed. Because of the extreme variation between products and environmental conditions, it is impossible to generalize about whether to use hydrogels or not. As with any products, growers or planters considering the use of hydrogels should conduct small scale trials under their own conditions. For root dips, just giving plants the added measure of care to keep roots moist increases outplanting performance.

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# The State and Challenges of Conservation Nurseries in Afghanistan

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Harrington JT, Mexal JG, Wagner AM, Parsons T. 2012. The state and challenges of conservation nurseries in Afghanistan. In: Haase DL, Pinto JR, Riley LE, technical coordinators. National Proceedings: Forest and Conservation Nursery Associations—2011. Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. Proceedings RMRS-P-68. 59-64. Available at: [http://www.fs.fed.us/rm/pubs/rmrs\\_p068.html](http://www.fs.fed.us/rm/pubs/rmrs_p068.html)

**Abstract:** Afghanistan is a semi-arid, mountainous country with a climate similar to New Mexico. Unfortunately, much of the country has been deforested by unsustainable fuelwood harvesting, overgrazing, and even concerns over security. The senior author was invited to assess the Afghanistan forestry situation in 6 provinces as part of the Afghanistan Water, Agriculture, and Technology Transfer (AWATT) program. The objectives of the assessment were to evaluate the capabilities of the Afghanistan nursery industry sites identified for reforestation; identify potential improvements to seedling production; and propose nursery research and development programs. Most seedling production is dedicated to ornamental or fruit tree production, with only a small percentage of seedlings destined for reforestation or restoration projects. Nurseries often lack basic resources such as a reliable source of irrigation, electricity for heating and cooling, and fertilizer. Better access to publicly available information could greatly improve seedling production practices with little expense.

**Keywords:** restoration, polybag, arid lands, deforestation, foster mum program

## Introduction

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Afghanistan, a country about the size of Texas, has many similarities to New Mexico; much of the area is arid or semi-arid and mountainous. New Mexico is approximately 25% forested; the original forest cover of Afghanistan was estimated to be about 48%. The eastern part of the country was historically conifer and oak forests, while the interior mid-elevation lands had pistachio (*Pistacia vera*) and juniper (*Juniperus* spp.) woodlands (Figure 1). Currently less than 2% of Afghanistan is forested. To provide perspective, in 1979, there were nearly 2 million ha (4.9 million ac) of forestland, with 1.3 million ha (3.2 million ac) of conifer forest and about 450,000 ha (1.1 million ac) of pistachio woodland. Today, estimates of both have been halved (Figure 2) (FAO 2010).

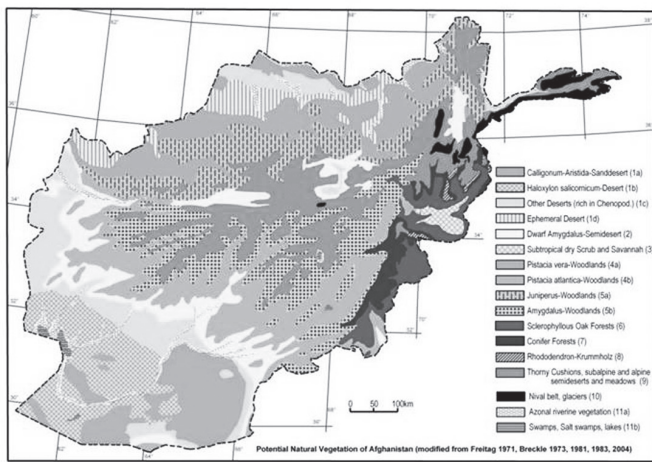


Figure 1. Vegetation types in Afghanistan.

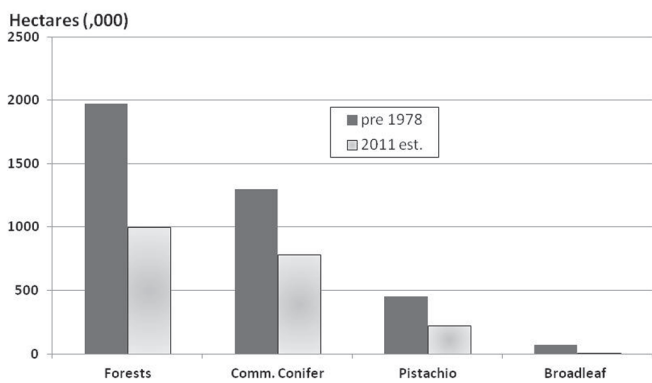


Figure 2. Land cover type in Afghanistan, pre-1978 and estimated for 2011.

While less than 2% of the country is classified as forest, approximately 45% has been classified as woodland/shrubland (FAO 2010). Poverty and conflict have contributed to deforestation of the country with few efforts toward sustainable forest management. Harvest for both industrial roundwood and fuelwood continues to increase despite decreased forest resources and the lack of a sustainable forest management strategy (Figure 3). In 2002, fuelwood harvest was over 40% of the total harvest; current estimates indicate over 80% of the total harvest is for fuelwood. In addition to unsustainable and illegal timber harvesting and excessive fuelwood harvesting, other factors contributing to deforestation include poor grazing practices that hamper natural regeneration and tree removal for security purposes (Figure 4).

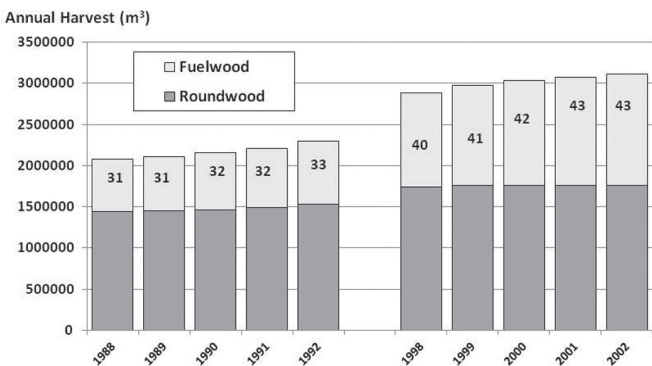


Figure 3. Change in industrial roundwood and fuelwood harvest for Afghanistan from 1988 through 2002 (FAO 2010). Number inside the bar is percentage fuelwood harvest of total harvest. 1 m³ = 35.3 ft³.

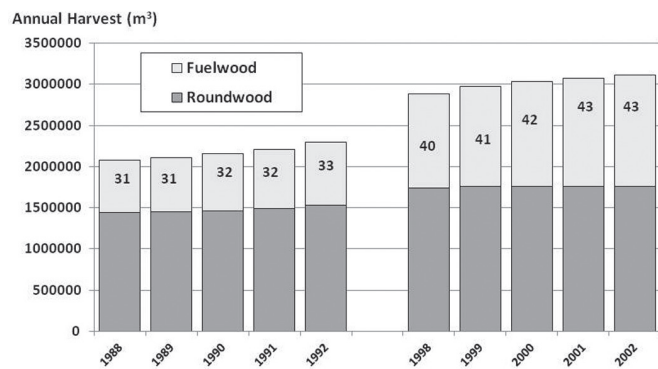


Figure 4. Impediments to forest restoration include: A) uncontrolled livestock grazing pressure; B) fuelwood harvest; and C) timber harvesting (likely illegal).

The senior author was invited to assess the Afghanistan forestry situation as part of the Afghanistan Water, Agriculture, and Technology Transfer (AWATT) program. The scope of work included review of existing nursery and planting conditions in AWATT project areas; providing technical expertise to develop an integrated conservation tree nursery program/network; and development of training materials for the improvement or development of nurseries. The assessment, consulting, and training occurred in 6 provinces, mostly in the eastern part of the country (Figure 5).



Figure 5. AWATT locations in Afghanistan for J Harrington, 2010 to 2011.

## Afghan Nurseries—an Overview

Twelve nurseries in eastern Afghanistan were visited (Table 1), and information was provided on an additional 18 nurseries in Kabul province (Table 2). Nurseries in Afghanistan are small; most produce less than 100,000 seedlings/year, and only two produce more than 500,000 seedlings/year. The target market for Afghan nurseries is primarily horticultural, specifically providing large seedlings for urban forestry and home gardening. The majority of the stocktypes are 2- to 3-year-old deciduous, bareroot seedlings, with prices ranging from 15 AFN (~US\$ 0.30) to 400 AFN (~US\$ 8.00). Bagged seedlings that are analogous to ball and burlap (BB) nursery stock in the United States are produced in some nurseries. Both deciduous and conifer seedlings produced in polybag containers are a third category of plant material produced at five nurseries.

A small percentage of planting stock is used for reforestation. Although most nurseries target their product to landscaping or agroforestry, one non-governmental organization (NGO) nursery did indicate that up to 50% of their plant material is used for reforestation. In

**Table 1.** Production characteristics of nurseries evaluated during the assessment. (1 ha = 2.5 ac)

Location (Province)	Nursery	Ownership	Size (ha)	Species	Bareroot	Ball and Bag	Container	Annual Production (estimate)
Kabul	Bibi Mahrow	MAIL/DAIL	<1	8	+	+	-	na
	Paghman	MAIL/DAIL	15	20	+	+	+/-	150,000
	Paghman	NGO-CDP-K	3.2	6	+	-	-	182,000
	11th Street	NGO-CDP-K	1.2	4	+	-	+	600,000
Balkh	Takhta Pul	MAIL/DAIL	8	12	+	+	+/-	270,000
	PDHP	PDHP	1.2	13	+	+	-	20,000
	PDHP-Mother Plant	PDHP	<1	na	+	+	-	na
	Private	Private	na	na	na	na	na	na
Nangarhar	Bagh-e-Ghulam Haidar	MAIL/DAIL	4	15	+	+	+	na
	Qurya e Jadid	MAIL/DAIL	4	20	+	+	+	na
	IF HOPE	NGO-IF HOPE	85	8	+	+	+	2,000,000
Hirat	Odoro Bagh	MAIL/DAIL	4	8	+	+	-	40,000
	Private	MAIL/DAIL	4	7	+	+	-	40,000

**Table 2.** Attributes of private Kabul nurseries, courtesy of CDP—Kabul (Community Development Program—Kabul).

District	Nurseries (number)	Production					Total
		Conifer	Deciduous	Riparian	Range		
					Min	Max	
Mirbachakot	8	130,300	85,200	63,500	200	150,500	279,000
Paghman	4	2,500	2,000	12,000	2,200	9,000	16,500
Farza	2	0	50	200	100	150	250
Estalif	1	0	1,500	0			1,500
Istalif	1	3,000	61,300	18,000			82,300
Qarabagh	1	500	2,900	6,500			9,900
Shkar dara	1	3,000	1,000	0			4,000
<b>TOTAL</b>	<b>18</b>	<b>139,300</b>	<b>153,950</b>	<b>100,200</b>			<b>393,450</b>

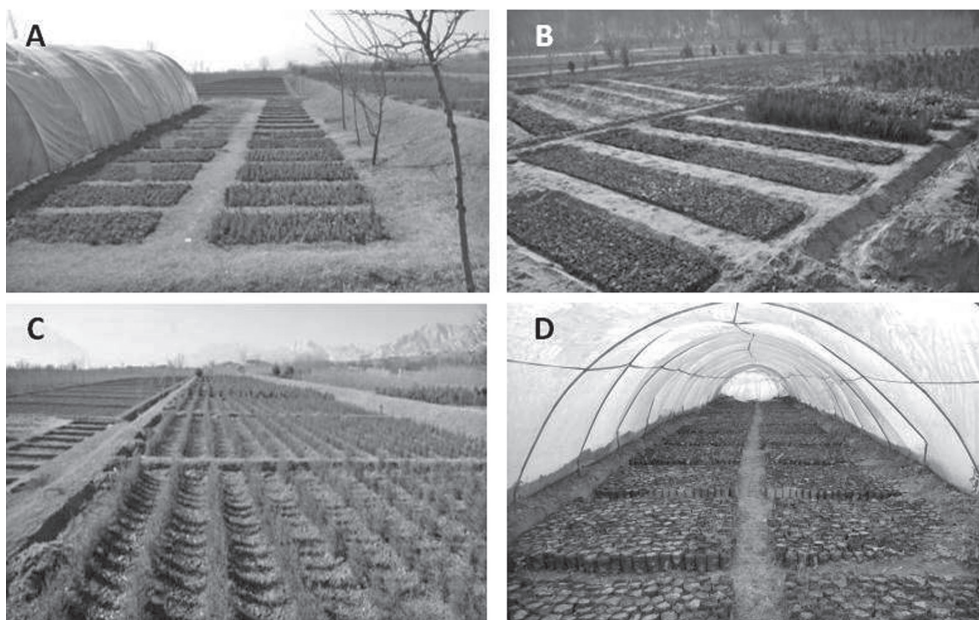
all but the 3 NGO nurseries, the majority of plants are being sold for the urban greening and fruit tree/agroforestry sectors. These horticultural markets require a larger product that commands a higher price than reforestation planting stock. Larger reforestation stock, however, can be less susceptible to grazing pressure following outplanting.

## Innovations

Most nurseries demonstrated some level of innovation to improve seedling production (Figure 6). For example, nurseries with limited water supplies used sunken beds with furrow irrigation. Almost all used a 2-tree row per furrow production strategy that increased overall production efficiency. Another innovation was the use of nursery plants for sources of cutting materials for vegetatively-produced plants. For instance, one nursery in Jalalabad used pruning residues from harvested *Punica granatum* seedlings as cutting material for the next production cycle. Other nurseries either had stooling blocks or adjacent landscape trees as a source of cutting material. Given the limited resources at nurseries, fertilizer use was limited. Several facilities did have composting programs to ameliorate the situation. Unfortunately, the volume of compost required is far greater than the capacity of the nurseries' composting infrastructure.

The nurseries also demonstrated considerable innovation in their propagation strategies. The use of seedbeds and transplant beds is an effective use of limited nursery space. Seeds are sown in a seedbed and seedlings are transplanted (pricked out) to transplant beds after as much as one growing season. Transplants are grown for 1 to 3 seasons before being sold. Nurseries used the transplant process as an opportunity to sort or grade seedlings, ultimately improving crop uniformity, decreasing production costs, and improving stock quality. One nursery started conifer stock in containers and then transplanted them into the transplant beds (similar to Plug + 1). This method might shorten the production cycle by 1 year. Seedlings grown in native soil are sold as bareroot or BB stock.

The use of polyethylene-covered high tunnels (poly tunnels) over seed beds was observed at several nurseries (Figure 6D). This low-cost technique extends the growing season during the first year, ultimately resulting in shorter production times. Greenhouses lack electricity, and therefore have only a limited ability to control environmental (temperature) conditions. These greenhouses would be analogous to cold frames or hoop houses in the United States. The primary use of these limited greenhouses appears to be to start seedlings in containers for the first growing season. Some polybag and container (clay pot) plant materials are grown in unheated greenhouses to extend the growing



**Figure 6.** Nursery practices in Afghanistan: A) in-ground seedbed nursery production; B) in-ground polybag production system; C) transplant seedling bed for bareroot or BB production; and D) high tunnel polybag production.

season. Innovative growers excavated the growing area to a depth of 1 m (3.3 ft) or more. This effectively insulates the crop and raises the temperature inside the greenhouse in winter.

Polybag production was variable. Use of polybags in nursery production can be considered as a positive innovation given the ability of intact rootballs to mitigate stresses associated with plant harvesting, transportation, and planting. The predominant polybag used was 12.5 cm (5 in) wide by 15 to 20 cm (6 to 8 in) deep. Polybags were used in two production strategies: 1) faster growing deciduous stock, such as *Eucalyptus* spp.; and 2) conifers produced in outdoor nursery beds for 1 to 3 years until they reached marketable size. Polybag seedlings, primarily conifers, were also grown in poly tunnels for 1 year then transplanted to the field nursery for the remainder of the production cycle, typically 2 to 3 more years. The growing media for polybag production typically consisted of native sand, soil, and compost (2:1:1).

## Limitations

Nursery limitations can be separated into infrastructure (capital) issues, and operational issues, including administration and personnel. The most significant and overarching capital limitation is the lack of reliable utilities, including water, electricity, and gas. Almost every process is done by hand, from bed preparation to seedling lifting. While mechanization has its advantages, the large potential work force in Afghanistan can be effectively used to offset the limitations associated with the lack of mechanization. Most nurseries also lacked greenhouses, and those with greenhouses lacked the ability to regulate temperature. While some nurseries did have a reliable water supply, most nurseries have had to take innovative steps, such as changing bed design or size, to make good use of their limited water supply.

The public nurseries appear to rely on public sales to sustain operations. The level of funding these nurseries receive from the government was unclear. The request from one such nursery for money to pay for laborers, fertilizer, and hand tools is indicative of the shortfall in operational funding. In contrast, the 3 NGO nurseries do not rely on public sales, and were appropriately staffed and had active annual fertilization programs. The impact of consistent

funding on the final product is evident in the overall uniformity of the plants being produced at the NGO nurseries.

Nursery personnel lacked access to currently accepted propagation practices and other advances in horticultural and conservation nursery operations. An example of this knowledge gap is the lack of seed refinement and seed pre-treatments. A better understanding of these aspects of propagation could improve seedbed space utilization and overall seed use efficiency. A second example is in the area of crop uniformity; at several nurseries there was considerable variability in crop size. Such variation resulted in partial bed harvesting and remnant trees being left in production beds until they reached a salable size, as much as one year later. Such practices decrease the overall production efficiency while increasing operational costs.

The size of conservation or reforestation planting stock produced in Afghanistan nurseries is much larger than conventional reforestation planting stock, that is, more similar to horticultural plant material. Poor handling of these large seedlings as they are lifted from the nursery beds and transported to outplanting sites tends to reduce stock quality.

## Opportunities for Improvement

There are two primary areas, irrigation and greenhouses, in which existing infrastructure can be modified to improve production efficiency with modest investment. Conversion to sprinkler or drip irrigation systems will require investment into pressurizing systems and expensive, high-maintenance filtration systems. Improving the existing flood and furrow/sunken bed irrigation system, however, will suffice to overcome current limitations without costly investment. For example, concrete lining of distribution ditches and installation of turnouts and individual bed gates would reduce the amount of water lost to seepage.

Limited-technology hoop houses or cold frames could also enhance efficiency. There are currently several nurseries that use these structures, referred to as greenhouses. With training and appropriate use of the structures, other nurseries could improve production efficiency. Using these limited-technology structures can also serve as an effective tool to increase the use of polybags in the production of reforestation planting stock.

## Nursery Protocols

Conifers are propagated from seeds that are sown in the fall or winter (Figure 7A). Typically, the seeds are sown in a seedbed and grown for 1 year, transplanted, and grown for an additional 2 to 4 years until they reach marketable size (1+2 or 1+4). The final product is typically sold as BB stock. There were some variants to this practice, including sowing seeds in polybags for 1 year and then transplanting into transplant beds (Plug+1), or starting the plants in seedbeds inside a high tunnel and then transplanting them after 1 growing season to the transplant beds. The underlying benefit of transplanting polybag-grown seedlings is the harvesting (lifting) process is less stressful to the plant, less expensive in terms of manpower, and results in greater production efficiency than digging and transplanting bareroot seedlings.

Bareroot deciduous seedlings are propagated from either cuttings or seeds (Figure 7B). When propagated from cuttings, the cuttings (whips) are collected while dormant, typically in late winter or early spring, and then planted (stuck) into the nursery beds. Depending on growth rates, the cuttings are raised to marketable size in 2 to 3 growing seasons. When propagated from seeds, sowing takes place in the fall or early winter for those species requiring stratification, or in early spring or shortly after seed dispersal for those with no stratification requirement. Seedlings are typically produced over 2 growing seasons (2+0).

Polybag production of deciduous species is limited to seed propagation of fast-growing species, such as *Eucalyptus* spp. Polybags are typically sold after 1 year; there were several nurseries in Nangarhar Province, however, where the seedlings were held for 2 years and were clearly oversized for the size of the polybag.

Several potential changes to the production regimes of bareroot seedlings could improve production efficiency or product quality. These changes incorporate greater use of polybag containers into various aspects of the production regime (Figure 7C). Ultimately, converting the final product to polybags should improve transplant performance due to: 1) increased protection of roots by the contained rootball; and 2) container-grown plants can have better transplant performance in arid and semi-arid planting sites.

Seed handling, specifically seed treatment, can also be addressed to improve plant production. All nurseries used natural environmental conditions (fall or winter sowing) to meet stratification requirements. None of the nurseries were using scarification techniques for species that require it, for example, black locust (*Robinia pseudoacacia*) and

Afghan redbud (*Cercis griffithii*). Relying only on natural stratification requires the seeds of many species to be sown shortly after collection. Artificial stratification and scarification treatments allow nurseries to spend more time to refine seeds, thus increasing the amount of viable seeds being sown. Artificial stratification can also be used to re-sow seeding beds with poor initial germination, a condition observed in several of the nurseries. Finally, species could be sown in the spring if scarified properly. Implementing scarification treatments is typically a cost-effective means to improve germination and production efficiencies.

Nurseries are producing healthy, quality planting stock (Figure 8 A, B, C). The lifting and handling processes, however, are likely degrading this quality quite dramatically. Nursery and transport personnel, as well as the end users, should be trained in the importance of careful handling. Training would need to focus on four principal areas: keeping roots moist and protected throughout the process; keeping plants cool throughout the process; using covers to protect the plants during transport; and ensuring that container or bagged plants have moist soil.

## Outplanting

Contour terracing, the dominant site preparation practice, seems to be the most effective means of combining site preparation and erosion control (Figure 8D). Many of the sites needing reforestation are so degraded that surface erosion rates have increased significantly. The loss of the nutrient-rich surface soil layer creates challenges to successful reforestation, as well as numerous other detrimental impacts throughout the associated watershed. The practice of contour terracing, while labor intensive, is effective at reducing surface erosion and runoff and improving infiltration at the planting sites. Several contacts reported survival was routinely high ( $\geq 90\%$ ). Site visits by the senior author, however, indicate a much lower success rate (Figure 8E). Some sites, such as those in Paktika Province, are so large and degraded that the potential for terracing may be limited. Other soil stabilization practices, such as direct seeding of grasses and shrubs, will need to be employed before trees can be successfully established. The sites will also need to be protected from grazing pressure until the trees are established.

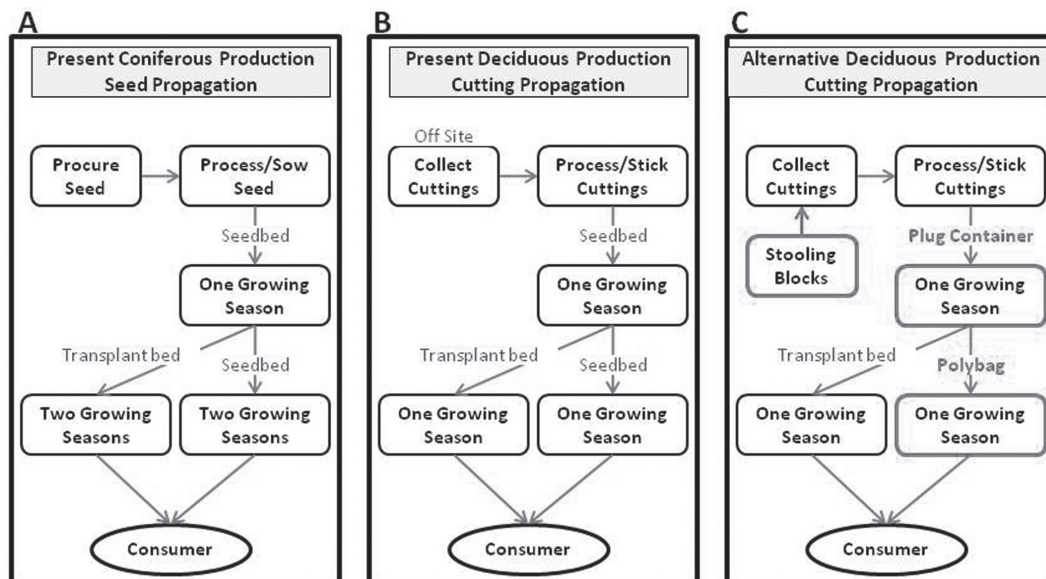
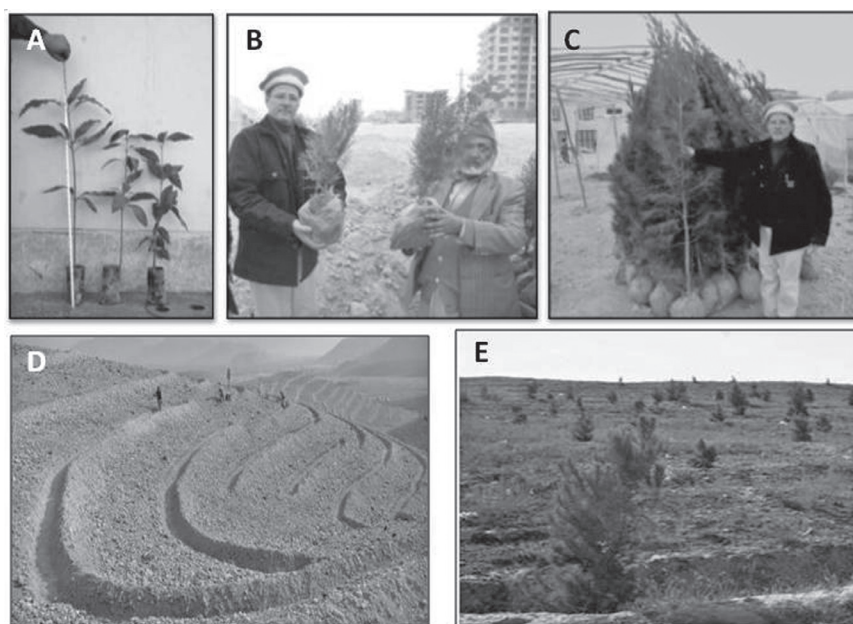


Figure 7. Schematic of current conifer and deciduous seedling production protocols and proposed alternative.



**Figure 8.** Representative seedlings produced in: A) polybag production; B, C) BB production; D) watershed restoration catchment trenches; and E) *Pinus halepensis* restoration.

## Research and Development

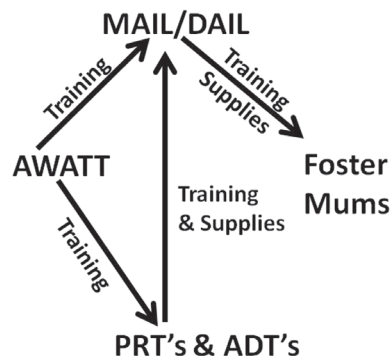
A nationwide nursery research and development program should be administered by the Ministry of Agriculture, Irrigation and Livestock (MAIL), possibly in conjunction with major universities in Afghanistan. The partnership is a logical one; universities have greater research capabilities, and the nurseries have a need for applied research and development. A MAIL/university partnership would provide a platform to bolster or develop a forestry/horticulture curriculum in the universities, developing a capacity for Afghanistan to train future forestry/horticulture professionals. The larger NGO and private nurseries may want to support an effort similar to that of nursery cooperatives in the United States. They could develop their own programs, but that would likely be more expensive and perhaps redundant.

Evaluating alternative production regimes, predominantly polybag production, should be conducted simultaneously with work on developing reforestation planting stock that matches the planting site. Polybag containers will continue to be the best alternative, given the prohibitive cost of rigid containers and artificial growing media. One important aspect of polybag production research that would need to be addressed is size. Various manufacturers produce different sizes of these bags. Because plants produced in polybag containers are prone to root spiraling, it will be important to address correct sizing of the polybags and production systems that produce plant sizes that reduce the risk of root spiraling. Harvesting, handling, and planting are other areas where significant gains in transplant survival and performance could be realized with nominal research and development expenditure. As with the research in production strategies, the majority of the foundation research in these areas has already been done elsewhere in the world. It is necessary to refine this information to meet the specific needs of Afghanistan.

## Additional Opportunities

The years of military conflicts have resulted in many widows with no source of income or support. One novel program is the “Foster Mum” program where families were provided with training and supplies to start small nurseries as a source of income (Figure 9). AWATT provided training to MAIL, the Directorate of Agriculture,

Irrigation, and Livestock (DAIL), Provincial Reconstruction Teams (PRTs), and Agribusiness Development Teams (ADTs). These programs then provided training to the families. This program will likely require ongoing support in the form of supplies (containers, seeds, fertilizer) and additional training.



**Figure 9.** Diagram of the organizational structure of the “Foster Mums” program in Afghanistan. AWATT is the Afghanistan Water, Agriculture, and Technology Training Program; MAIL is the Ministry of Agriculture, Irrigation, and Livestock; DAIL is the Directorate of Agriculture, Irrigation, and Livestock; PRTs are the Provincial Reconstruction Teams; and ADTs are the Agribusiness Development Teams.

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The content of this paper reflects the views of the authors, who are responsible for the facts and accuracy of the information presented within.



# Restoration Potentials and Challenges for *Sphaeralcea munroana*

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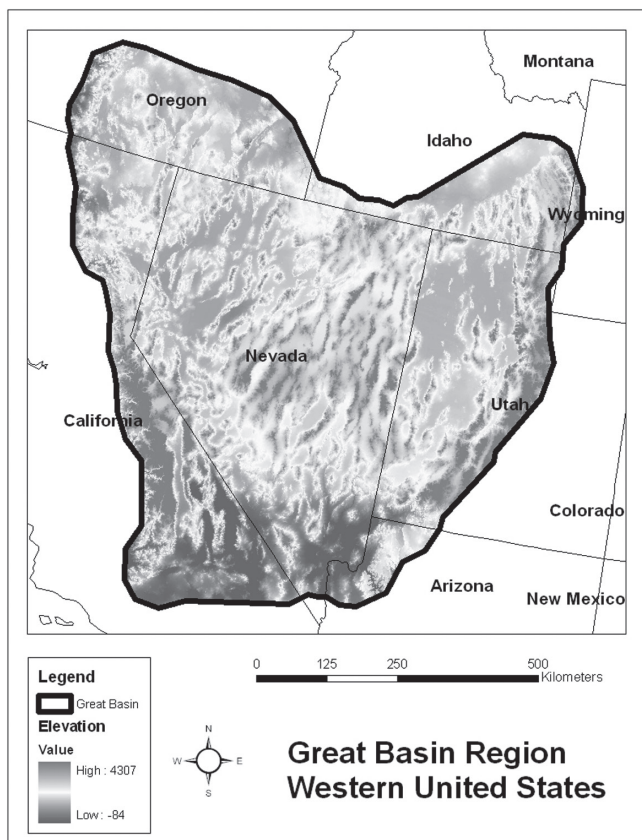
**Abstract:** Munro's globemallow (*Sphaeralcea munroana* [Douglas] Spach) is an herbaceous perennial and an important candidate for use in restoration due to its ecological significance and environmental resilience. The species' popularity among growers and land managers has recently increased but there is still a lack of information regarding seed dormancy and early seedling physiology, making the effective use of the species difficult. This paper provides a review of existing literature on *S. munroana*'s habitat, restoration potential, seed dormancy, and seedling physiology.

**Keywords:** Physical dormancy, physiological dormancy, Munro's globemallow, Great Basin, seedling physiology, Malvaceae

## Introduction

The arid-steppe of North America's Great Basin (Figure 1) is delineated by the Colorado and Columbia Plateaus, the Sierra Nevada Mountains, and the Mojave Desert. The region's unique geomorphology has a considerable effect on the climate, which is dominated by temperature extremes and low, primarily winter, precipitation (Knapp 1996). The vegetative communities of this area are characterized by the presence of shrubs, perennial bunchgrasses, and forbs (Holmgren 1972).

As an ecological unit, the Great Basin has suffered from substantial disturbance and fragmentation as a result of overgrazing, shrub removal, and non-native plant introduction (Mack 1981). Natural fire suppression over several decades and the rampant spread of cheatgrass (*Bromus tectorum* L.) have been linked to a 4 to 10 fold increase in fire incidence in the course of the last century (D'Antonio and Vitousek 1992). Frequent fires have promoted a widespread system conversion from sagebrush- to annual grass-dominated communities, which has reduced the available soil moisture, contributed to nutrient depletion, and increased resource competition (Billings 1990; Whisenant 1990; D'Antonio and Vitousek 1992; Obrist and others 2003). By recent estimates, the rate of habitat loss significantly exceeds the rate of ecosystem recovery, further threatening the populations of sagebrush-steppe obligates (i.e. pygmy rabbit, greater sage-grouse, and Brewer's sparrow) (Wisdom and others 2005; Parkinson 2008). In addition, the predicted rise in CO<sub>2</sub> has been projected to enhance biomass production of C<sub>3</sub> annual grasses, which could further exacerbate ecosystem conversion (Smith and others 1987; Smith and others 2000; Grunzweig and Korner 2001). As a result, the use of endemic plant species in restoration of disturbed sites in the Great Basin is critical in promoting ecological recovery.



**Figure 1.** General outline of the Great Basin region of the Western United States.

Herbaceous perennials comprise a substantial portion of the Great Basin floristic communities and are an integral component of these systems. The use of native species in restoration is optimal because they are evolutionarily adapted to withstand severe climate conditions, provide long-term soil stabilization, and foster habitat biodiversity. Despite the importance of their role, the use of forbs in habitat restoration is relatively novel and largely unexplored (Parkinson 2008). One such species, Munro's globemallow (*Sphaeralcea munroana* (Douglas) Spach) (Malvaceae), is a desirable candidate for revegetation; however, its use is constrained by the lack of information regarding its requirements for successful germination and establishment.

## Species Overview

*Sphaeralcea munroana* is a cool-season herbaceous perennial endemic to the Great Basin. Plants initiate growth from a caudex in the form of multiple, unbranched stems and typically reach 20 to 80 cm (8 to 30 in) in height. Showy, orange inflorescences are produced from May to August. Subsequent seeds are arranged in a schizocarp, composed of 10 to 12 mericarps that form a ring, each containing 1 to 2 pubescent seeds 1.5 mm (0.06 in) in length (Rydberg 1917; Lyons 1995). *S. munroana* is able to establish on disturbed sites and survive drought and temperature extremes. In addition to its resilience, this plant is an essential forage source for numerous rodents, lagomorphs, and ungulates (Beale and Smith 1970; Pendery and Rumbaugh 1986; Rumbaugh and others 1993; Pavék and others 2011). Furthermore, it provides nutrition for 20 generalist and 3 specialized (*Diadasia diminuta*, *D. lutzi*, and *Colletes sphaeralcea*) bee species (Cane 2008). These attributes have made *S. munroana* an important candidate for broad-scale restoration across its native range.

To date, seed dormancy of *S. munroana* has presented a major limitation to both in situ and ex situ germination. Several studies have

explored the dormancy mechanisms and methods for dormancy break in the *Sphaeralcea* genus, but much still remains ambiguous (Page and others 1966; Roth and others 1987; Kildisheva and others 2011; 2012). Moreover, little is known about seedling tolerance to temperature and moisture stress. Ehleringer and Cooper (1998) suggest that desert globemallow (*S. ambigua* A. Gray), native to the Mojave Desert, is "a short-lived, opportunistic species that establishes during wet years but demonstrates higher mortality during dry years due to relatively low water use efficiency". Whether this life strategy is shared by *S. munroana* is unclear. Plant establishment is the most critical phase in determining future survival and persistence (Harper 1977); thus, seedling post-germination responses to temperature and moisture stress are especially important.

## Seed Dormancy

Vleeshouwers and others (1995) suggest that dormancy is "a seed characteristic, the degree of which defines what conditions should be met to make the seed germinate". This is an evolutionary response to temporal variation in environmental conditions, which allows for different species to be favored over time (Rees 1996). Several types of dormancy exist and are defined based on the mechanisms that prevent germination.

Physical dormancy is common among desert species (including several in the *Sphaeralcea* genus) and is thought to have developed to prolong seed longevity (Page and others 1966; Sabo and others 1979; Roth and others 1987; Baskin and Baskin 1998; Smith and Kratsch 2009). Physically dormant seeds often possess a palisade layer of lignified cells that prevent water entry into the seed (Corner 1951; Vazquez-Yanes and Perez-Garcia 1976). Water imbibition is critical because it drives seed expansion (necessary for germination) and is dependent on the interaction between the growth potential of the embryo and the constraints imposed by the seed coat (Kucera and others 2005). Imbibition in many seeds with physical dormancy is regulated by a specialized anatomical structure, defined as the "water gap", which is located within the seed coat. The water gap becomes permeable when exposed to temperature flux, drying, or scarification, thus allowing imbibition into an otherwise impermeable seed (Baskin and Baskin 1998; Baskin and others 2000). The location, anatomy, and morphology of the water gap demonstrate intra- and extra-family variability (Baskin and others 2000). The chalazal region has been documented as a critical site for water entry in a number of *Malvaceae* species, including *Abelmoschus esculentus* (L.) Moench, *Gossypium hirsutum* L., *Sida spinosa* L. (Christiansen and Moore 1959; Egle and Paul 1981; 1982; Serrato-Valenti and others 1992) and more recently in *Sphaeralcea munroana* (Kildisheva and others 2011). In these species, the water gap is obstructed by 2 tissue types. Maternal tissue forms a cap that projects downward into the chalazal slit and mesophyll tissue projects upward. At the initiation of dormancy break, a section of these tissues that radially surround the chalazal slit become partially permeable and allow imbibition, which leads to a separation of the palisade and sub-palisade layer of cells causing the formation of a blister (Serrato-Valenti and others 1992). At the point when water surrounds the entire palisade layer of the seed coat, the mesophyll cracks, allowing the upper portion of the palisade cells to continue swelling. This process eventually causes a detachment of the blister roof, allowing for full imbibition (Serrato-Valenti and others 1992).

Natural phenomena, such as abrasion by sand and stones (in rapidly moving washes during periods of flooding), temperature fluctuations, fires, and animal digestion are thought to alleviate physical dormancy (Went 1955; Gutterman 1993; Baskin and Baskin 1998).

A number of ex situ techniques (Table 1), primarily chemical and mechanical scarification, have been used to promote germination of physically dormant species (Page and others 1966; Roth and others 1987; Hoffman and others 1989; Baskin and Baskin 1998). Page and others (1966) observed an average of 35% germination improvement of two accessions of *S. grossulariifolia* (Hook. & Arn.) Rydb. following submergence in sulfuric acid compared to the control (0%). Correspondingly, a 10 min submergence of *Sphaeralcea* seeds in 18 M sulfuric acid increased germination of *S. coccinea* (Nutt.) Rydb. (77%) and 2 accessions of *S. grossulariifolia* (69 and 62%) compared with the control (5, 14, and 32%, respectively), but did not improve germination of *S. munroana* (8%) relative to the control (2%) (Roth and others 1987). Additionally, organic solvents have been successful at alleviating dormancy in species with impermeable seed coats. A 4-hr submergence in diethyl dioxide improved germination of *S. grossulariifolia* to 67% compared with 0% reported for untreated seeds (Page and others 1966). Roth and others (1987) also note that a 3-hr soak in diethyl dioxide significantly enhanced germination of *S. coccinea* (36%), *S. munroana* (53%), and 2 accessions of *S. grossulariifolia* (89 and 68%) compared with the control (5, 2, 14, and 32%, respectively). Despite its efficacy, chemical scarification can be hazardous, cause embryo damage, and present serious health risks to humans (Mallinckrodt Baker 2008 a, b). As a result, alternative methods of seed treatment may be desirable.

Another technique for improving imbibition of impermeable seeds is through wet heat scarification. Emergence in boiling water improved seed permeability of several *Malvaceae* species, presumably by unblocking the water gap (Christiansen and Moore 1959; Baskin and Baskin 1997, Kildisheva and others 2011). For example, seeds of *Iliamna corei* Sherff (*Malvaceae*) germinated to 93% (as compared to 0% germination of the control), following a 5-sec submergence in boiling water (Baskin and Baskin 1997).

Higher germination has also been achieved by mechanical scarification. The International Seed Testing Association (ISTA) suggests the use of scarification to break physical seed dormancy of *Althaea* hybrids (*Malvaceae*) (ISTA 2011). Similarly, seeds of *I. corei* germinated to 100% following manual scarification with a single edge razor blade (Baskin and Baskin 1997). Scarification with a blade followed by submergence in water for 24 hours resulted in 93% germination of *S. munroana* seeds (Kildisheva and others 2011). Although effective, these techniques are time consuming and unrealistic for use as operational seed treatments.

A number of mechanical scarification methods designed for treating large seed quantities exist; however, few have proven to be successful in alleviating dormancy in *Sphaeralcea* species. Primarily a result of scarification severity, embryo damage often overshadows the dormancy-breaking effects of the treatment. Page and others (1966) report decreases in germination of *S. grossulariifolia* with the duration of scarification time in a sandpaper-lined rotating drum, while Roth and others (1987) suggest that seeds of *S. grossulariifolia*, *S. coccinea*, and *S. munroana* perished following mechanical scarification, regardless of treatment duration. More recently, rotating rock tumblers filled with abrasive media have been used to promote germination of some physically dormant species, providing a potential alternative to traditionally used scarification techniques (Dreesen 2004). However, Kildisheva and others (2012) found 72 hour tumbling with dry aluminum oxide grit ineffective in creating significant germination improvements in germination behavior of *Sphaeralcea munroana*. While, Smith and Kratsch (2009) observed only a minor increase (21%) in germination following a 24-hr tumbling of *S. abmigua*, *S. coccinea*, and *S. munroana* seeds.

Other less traditional techniques, such as fire and heating treatments, may be employed to effectively induce permeability in physically dormant seeds. For example, *I. corei* demonstrated increased germination

**Table 1.** Summary of seed treatments for breaking dormancy in *Sphaeralcea* species

Species	Seed Treatment	Germination (versus the control)	Source
<i>Sphaeralcea ambigua</i>	Source	45% v. 18%	Dunn 2011
	Mechanical scarification	36% v. 18%	Dunn 2011
<i>Sphaeralcea coccinea</i>	Diethyl dioxide (3 hours)	38% v. 5%	Roth and others 1987
	Mechanical scarification + 30-day stratification	85% v. 5%	Dunn 2011
	Mechanical scarification	52% v. 5%	Dunn 2011
	Sulfuric acid + diethyl dioxide (3 hours)	67% v. 5%	Roth and others 1987
	Sulfuric acid (10 minutes)	77% v. 5%	Roth and others 1987
<i>Sphaeralcea grossulariifolia</i>	Diethyl dioxide (3 hours)	80% v. 23%	Roth and others 1987
	Diethyl dioxide (4 hours)	67% v. 0%	Page and others 1966
	Mechanical scarification	47% v. 0%	Page and others 1966
	Sulfuric acid (up to 30 minutes)	35% v. 0%	Page and others 1966
	Sulfuric acid (10 minutes)	66% v. 23%	Roth and others 1987
<i>Sphaeralcea munroana</i>	Boiling water	49% v. 11%	Kildisheva and others 2012
	Diethyl dioxie (3 hours)	38% v. 2%	Roth and others 1987
	Sulfuric acid + diethyl dioxide (6 hours)	29% v. 2%	Roth and others 1987
	Mechanical scarification + 24-hour soak in water	93% v. 17%	Kildisheva and others 2011
<b>Combined lot:</b> <i>Sphaeralcea ambigua</i> , <i>S. coccinea</i> , <i>S. munroana</i>	Mechanical scarification + 6 week stratification	84% v. 5%	Smith and Kratsch 2009
	Mechanical scarification	52% v. 5%	Smith and Kratsch 2009
	Rock Tumbling (24 hours)	26% v. 5%	Smith and Kratsch 2009

Only treatments resulting in significant ( $p < 0.05$ ) improvements in germination relative to the control are reported.

following simulated annual summer burning (1 to 2 min), with the highest germination achieved after 6 years ( $39 \pm 6\%$ ) compared with the control (0%) (Baskin and Baskin 1997). In some cases, dry heat may be a substitute for fire, often achieving better results. For example, Baskin and Baskin (1997) found that several dry heat temperatures and exposure durations optimized the germination of *I. corei*.

Although the majority of physically dormant species do not exhibit additional dormancy, some do, including several members of *Malvaceae* (Baskin and Baskin 1998). Physiological dormancy, frequent in cold desert forbs, describes seeds that possess embryos with low growth potentials. This condition is caused by the presence of chemical inhibitors and can be relieved by stratification (Baskin and Baskin 1998). Gibberellic acid (GA3) has successfully served as a proxy for stratification for a number of physiologically dormant species (Timson 1966; Pinfield and others 1972). The exogenous application of GA3 is thought to enhance germination by increasing the growth potential of the embryo and by overcoming the mechanical constraints that prevent radical emergence (Karsen and others 1989; Hilhorst and Karssen 1992; Hilhorst 1995; Bewley 1997; Koornneef and others 2002; Leubner-Metzger 2003). In addition, exogenous application of GA3 alone, or in combination with scarification, significantly amplified the germination capacity of several species in the *Cactaceae*, including *Cereus spp.*, *Echinocactus grusonii* Link and Otto, Hildman and Monats, *Leuchtenbergia principis* Hook., *Sclerocactus mariposensis* (Hester) Taylor, and *Harrisia fragrans* Small (Krulik 1981; Moreno and others 1991; De La Rosa-Ibarra and Garcia 1994; Dehgan and Perez 2005). However, recent evidence (Kildisheva and others 2011) suggest that the treatment of *S. munroana* seeds with GA3 alone or in combination with scarification does not provide any additional benefits to germination, suggesting a lack of influence of chemical inhibitors on germination.

Some authors suggest (Dunn 2011; Smith and Kratsch 2009) that in addition to being physically dormant, seeds of *Sphaeralcea* species also exhibit physiological dormancy. The mixture of physical and physiological dormancy is called combined dormancy and requires physical dormancy to be broken prior to breaking physiological dormancy in order to allow for seed imbibition (Nikolaeva 1969; Baskin and Baskin 1998). Dunn (2011) observed improvements in germination of *Sphaeralcea ambigua* (45%) and *S. coccinea* (85%) following the combination of scarification and a 30-d stratification relative to the control (18 and 5%, respectively). Smith and Kratsch (2009) suggest that a 6-wk stratification of scarified seeds of *S. grossulariifolia*, *S. parvifolia* A. Nelson, and *S. munroana* resulted in greater germination than from either treatment alone. However, Kildisheva and others (2011) failed to find similar results following the combination of scarification and 6-wk stratification of *S. munroana* seeds; suggesting that other factors (i.e. storage conditions, seed collection timing, or climatic features during seed set) likely play a significant role in dormancy development and should be further explored.

## Temperature and Moisture as Limiting Factors to Seedling Development

In regions where growing conditions are limiting, plant establishment is the most vulnerable phase in vegetative community development (Call and Roundy 1991). In the arid-steppe ecosystem of the Great Basin, broad diurnal temperature fluctuations, periodic precipitation pulses, and significant droughts impose key restraints to post-germination survival. The maximum temperature and soil moisture variations take place in close proximity to the soil surface,

making seedlings more susceptible to environmental fluctuations than mature plants (Bazzaz and Mezga 1973; Raynal and Bazzaz 1973; Regehr and Bazzaz 1976). Thus, opportunities for plant establishment in the Great Basin are strongly limited by its environmental conditions.

Diurnal temperature can vary by 20 °C (36°F), while seasonal differences can be on the order of 40 °C (72°F) (Smith and Nowak 1990). These oscillations can be made even greater throughout the year by the nocturnal cold air drainage which are a feature of this region's topography (Osmond and others 1990). The Great Basin-Mojave system is described as the most xeric habitat in North America, with precipitation ranging between 50 and 300 mm (2 and 12 in) annually. Due to low humidity and abundant irradiance the rate of potential evapotranspiration is high, averaging between 1100 and 2000 mm (43 and 79 in) in the northern and southern sections of the basin, respectively (Flaschka and others 1987). Summer precipitation is highly variable, generally accounting for only 20 to 30% of total annual precipitation (Bell 1979). A substantial portion of the available moisture is significantly depleted by the time atmospheric and edaphic conditions become suitable for plants to be fully physiologically active; thus, there is a temporal difference between maximum water availability and the ability of plants to use it (Caldwell 1985). The combined effects of precipitation and temperature patterns result in substantial implications with regard to the physiology of the native plant communities. The start of the growing season in this region is directly associated with the rise in temperatures and the amount of available winter-spring precipitation, making the time of growth initiation in the spring critical (Turner and Randall 1987). Most species begin growth in March and April, a time when maximum daily temperatures range between 5 and 15 °C (41 and 59 °F) and night temperatures persist near 0 °C (32 °F) (Thornthwaite 1948; Comstock and Ehleringer 1992).

Plant photosynthetic rates demonstrate substantial temperature dependence. At low temperatures, photosynthetic rates are reduced due to the decline in enzyme-catalyzed reaction rates. As temperatures rise, carbon assimilation rises until a maximum (defined as a "temperature optimum") is reached, and declines once the optimum has been exceeded (Comstock and Ehleringer 1992). The maximum photosynthetic rates exhibit considerable variability, and are primarily governed by environmental conditions. At the beginning of the growing season, when day-time temperatures do not exceed 20 °C (68 °F), the temperature optimum for many Great Basin shrubs is 15 °C (59 °F), increasing by 5 to 10 °C (9 to 18 °F) later in the season (Caldwell 1985). The maximum CO<sub>2</sub> assimilation rates of shrubs native to this region, under natural or irrigated conditions, range from 14 to 19 μmol CO<sub>2</sub> m<sup>-2</sup> s<sup>-1</sup> (Deputit and Caldwell 1973; Caldwell and others 1977). At this time, most research has focused on examining the photosynthetic behavior of perennial shrubs, with little attention given to herbaceous species. However, the phenological cycles of herbaceous and woody perennials are different, and may be expressed through variation in photosynthetic behavior.

The increasing prominence of native forbs in restoration programs requires a clear understanding of the physiological ecology of these species. Furthermore, knowledge regarding the photosynthetic behavior of members of the *Malvaceae* family is lacking. In a cultivation setting, *Sida spinosa*, *Gossypium herbaceum* auct. non L., and *Gossypium arboreum* L., demonstrate relatively high CO<sub>2</sub> compensation points that are associated with large net CO<sub>2</sub> fixation and faster growth rates (Chen and others 1970). In the Great Basin, however, rapid growth rates can create severe internal moisture deficits, making the ability of plants to effectively regulate moisture loss imperative.

In general, low spring temperatures allow for higher water-use efficiency as cold soils reduce leaf conductance, but freezing night

temperatures prevent full reduction in stomatal opening during the day, when moisture loss is high (Smith and Novak 1990). As soil moisture deficits increase with seasonal warming, plant water content declines, resulting in a lower turgor pressure. Under these conditions, turgor-dependent processes such as leaf expansion and root elongation are suppressed. Decreases in turgor have been linked to reductions in aboveground plant area and overall growth rates (Taiz and Zeiger 2006). Moisture restrictions cause a greater portion of photosynthates to be distributed to the root system, promoting belowground biomass production. Thus, root-to-shoot ratios (R:S) are a direct result of a dynamic equilibrium between water uptake and photosynthesis (Taiz and Zeiger 2006). R:S of desert perennials exhibits considerable variability among species, ranging from 0.15 to 6.77, with lower R:S values characteristic of plants in the northern Great Basin as compared to much higher ratios for plants found in the Mojave and Sonoran Deserts (Barbour 1973; Caldwell and others 1977). To date, most research has characterized mature perennial shrub and grass species, while much less is known about growth dynamics of forbs, especially shortly following establishment. A recent study examining the effects of 2 temperature (17/3 °C and 23/9 °C [ 63/37 °F and 73/48 °F]) and 4 moisture regimes (3-, 6-, 9-, and 12-d irrigation interval) on seedling responses of *S. munroana* 35 days following establishment suggest that low diurnal temperatures impacted growth immediately after germination to a greater extent than did available moisture (Kildisheva and Davis 2012). Seedlings grown under the warmest, most arid conditions reduced their aboveground biomass while increasing belowground biomass production, with no changes in gas exchange rates; indicating high drought tolerance even during early development (Kildisheva and Davis 2012). Thus, *S. munroana* exhibits considerable potential for restoration use on arid sites, but may be a sub-optimal competitor with cool season grasses in the spring, and may benefit from later sowing when night temperatures are above 3 °C (37 °F) (Kildisheva and Davis 2012). However, resilience early in the growing season doesn't necessarily indicate long-term survival; thus, further research which relates growth rates at the beginning of the season to consequent survival and phenology is essential.

## Conclusions

Considering the rate of habitat degradation in the Great Basin, revegetation with native plants is integral to ecosystem function and resilience. *Sphaeralcea munroana* is a species with a high restoration potential; but the success of its use requires a better understanding of seed dormancy, storage conditions, and collection timing. Furthermore, the Great Basin climate is characterized by wide diurnal temperature fluctuations, episodic precipitation pulses, and extensive droughts which can severely limit seedling establishment and survival; thus, research linking early seedling performance with future growth and phenology is necessary.

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# Eco-Buffers: A High Density Agroforestry Design Using Native Species

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**Abstract:** This study showed that Eco-Buffers are characterized by rapid establishment and superior survival when compared to single species buffers. Height of green ash (*Fraxinus pennsylvanica* Marsh. var. *subintegerrima* (Vahl.) Fern.) after eight growing seasons averaged 415 cm when growing in an Eco-Buffer compared to 333cm in the single species buffer. Site capture in the Eco-Buffer was 100 percent after eight years whereas the single species buffer had heavy herbaceous weed understory. In eight years plant density increased from 5000 to 35,000 plants/ha plants in the Eco-Buffer compared to a decline from 3500 to 3250 plants/ha with the single species design. This was due in large part to the development of rhizome shoots with pin cherry (*Prunus pensylvanica* L.), choke cherry (*Prunus virginiana* var. *melanocarpa* (A. Nels.) Sarg.) and Wood's rose (*Rosa woodsii* Lindl.). The study showed that Eco-buffers establish more quickly and out-compete herbaceous competition resulting in superior growth compared to single species shelterbelts.

**Keywords:** buffer, design, shelterbelt, establishment, hedgerow

## Introduction

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The predominance of large-scale agriculture and the introduction of precision farming technology have led to increased field size and a noticeable reduction in marginal habitats within, and adjacent to, agricultural fields. This has occurred mainly at the expense of naturally occurring hedgerows, woodlots, and wetlands. In some regions, where conservation tillage has reduced the threat of wind erosion, there has been removal of planted shelterbelts with the objective of increasing field size to facilitate the use of large equipment. An impact of the implementation of these production system changes is that the role of shelterbelts and hedgerows in agricultural may need to be re-defined from solely wind erosion protection to multi-purpose functions such as carbon sequestration, land and water protection, and biodiversity enhancement.

Woody hedgerows and small wooded areas present important refuge for native flora and fauna. In Canada, three types of woody field boundaries can be found: 1) planted shelterbelts, normally consisting of a single row of one species, primarily planted for wind erosion control; 2) natural woody hedgerows such as those remaining from larger cleared woodlands and left to grow naturally between agricultural fields; and 3) herbaceous fencerows with few trees and scattered shrubs. In the Canadian prairies, over 160,000 hectares of shelterbelts, predominately caragana (*Caragana arborescens* Lam.) and green ash (*Fraxinus pennsylvanica* Marsh. var. *subintegerrima* (Vahl.) Fern.), have been planted since the early 1900s (Schroeder and others 2008).



## Eco-Buffers

The Agroforestry Development Centre (Saskatchewan, Canada) has been conducting research to develop alternative tree planting designs particularly for field boundary planting with the purpose of enhancing biodiversity, conserving soil, protecting water quality, and sequestering carbon. Multi-species, row shelterbelts have been used in the United States (Baer 1986) and Europe (Schroeder and Kort 1989) with success. These initiatives primarily concentrate on planting narrow, dense shelterbelts that establish quickly and reduce the need for long-term weed control. Considering the advantages of mixed-species shelterbelt designs used in other regions, our goal was to develop a design that resembles natural hedgerows, establishes quickly, and develops into a biologically diverse buffer. The field boundary design being researched by AAFC-AESB (Agriculture and Agri-Food Canada, Agri-Environment Services Branch) has been given the descriptive name Eco-Buffer. Eco-Buffers are multiple rows of a variety of trees and shrubs in a mixed-planting arrangement. This design can be applied where a traditional shelterbelt would be planted or a natural hedgerow may have existed. Eco-Buffers can also be used to supplement or rehabilitate existing natural hedgerows or to connect natural habitats. In addition to their ecological function of wind erosion control, microclimate modification, pollination services, wildlife habitat, and carbon sequestration, Eco-Buffers provide a source of wood and non-timber forest products (e.g. fruit and mushrooms).

Eco-Buffers consist of a variety of species with variable characteristics such as thorns, spreading rhizome shoots, fast and slow growth, and varying flowering periods. Three types of woody plants are used in the design: 1) long-lived, climax-species trees every sixth plant in middle rows, e.g. ash, spruce, pine, oak; 2) fast growing, short-lived trees planted in middle rows, e.g. poplar, maple, mountain ash; 3) tall shrubs planted in middle rows with spreading rhizomes to quickly capture the site, e.g. cherry, hawthorn, elder; and 4) small and medium shrubs planted in outside rows consisting of flowering species for pollination, e.g. rose, snowberry, potentilla. The Eco-Buffer includes a minimum of four to five shrub species and every sixth plant is a long-lived tree. A range of native tree and shrub species can be used in Eco-Buffers. Species choice depends on what trees and shrubs grow naturally in the area where the Eco-Buffer will be established.

Our study objectives were to compare growth and development of tree and shrub species planted in an Eco-Buffer with those planted in a traditional shelterbelt design and to develop guidelines for species composition and arrangement in an Eco-Buffer design. Our goal is to develop a tree/shrub buffer design that increases ecological function of planted shelterbelts and hedgerows.

## Methods

The study was planted at the Agriculture and Agri-Food Canada Experimental Farm near Indian Head, Saskatchewan. The two study treatments were: 1) Eco-buffer design, and 2) traditional multi-row shelterbelt design. The five-row Eco-Buffer treatment included Wood's rose (*Rosa woodsii* Lindl.), red-osier dogwood (*Cornus stolonifera* Michx.), green ash, round-leaf hawthorn (*Crataegus rotundifolia* Moench), choke cherry (*Prunus virginiana* var. *melanocarpa* (A. Nels.) Sarg.), pin cherry (*Prunus pensylvanica* L.), aspen (*Populus tremuloides* Michx.), and box elder (*Acer negundo* L.). The traditional design included caragana, green ash, and white spruce (*Picea glauca* (Moench.) Voss.). The species used in the study are described in Table 1 and species arrangement for the Eco-Buffer and traditional designs are illustrated in Tables 2 and 3. In-row spacing for trees and shrubs in both treatments was 1 m (3.2 feet) with between-row spacing of 3 m (9.8 feet). Each treatment plot was 36 m (118 feet) in length. The study was arranged in a randomized complete block design with four replications.

Trees were machine planted in early June, 2004. All deciduous trees and shrubs were dormant 2-0 bare root seedlings, white spruce were 2-3 bareroot seedlings. Prior to planting, a pre-emergent herbicide mixture (trifluralin + metribuzin) was applied to the site. Weeds were controlled in year one with two tillage operations (July and September). During years two and three, weeds were controlled with one tillage operation (August) and one application of glyphosate using a shrouded sprayer (September). There was no weed control after year three.

After eight growing seasons, 6-m (19.7-feet) wide transect plots were set up across each buffer design treatment plot. Height of all trees and shrubs in the plot were measured and the number of rhizome shoots with a root collar diameter greater than 7 mm (0.28 inch) was

**Table 1.** List of tree and shrub species used in buffer designs

Genus and Species	Common Name	Category	Eco-Buffer	Traditional
<i>Rosa woodsii</i>	Woods' rose	Small shrub	X	
<i>Cornus stolonifera</i>	Dogwood	Small shrub	X	
<i>Crataegus rotundifolia</i>	Hawthorn	Medium shrub	X	
<i>Caragana arborescens</i>	Caragana	Medium shrub		X
<i>Prunus virginiana</i>	Choke cherry	Medium shrub	X	
<i>Prunus pensylvanica</i>	Pin cherry	Tall shrub	X	
<i>Populus tremuloides</i>	Aspen	Short-lived tree	X	
<i>Fraxinus pennsylvanica</i>	Green ash	Long-lived tree		X
<i>Acer negundo</i>	Box-elder	Long-lived tree	X	
<i>Picea glauca</i>	White spruce	Long-lived tree		X

**Table 2.** Species arrangement in the Eco-Buffer design.

Row 1	Row 2	Row 3	Row 4	Row 5
Woods' rose	Pin cherry	Aspen	Pin cherry	Woods' rose
Woods' rose	Green ash	Choke cherry	Green ash	Woods' rose
Woods' rose	Hawthorn	Aspen	Hawthorn	Woods' rose
Dogwood	Aspen	Pin cherry	Aspen	Dogwood
Green ash	Choke cherry	Green ash	Choke cherry	Green ash
Dogwood	Aspen	Choke cherry	Aspen	Dogwood
Woods' rose	Pin cherry	Aspen	Pin cherry	Woods' rose
Woods' rose	Box-elder	Choke cherry	Box-elder	Woods' rose
Woods' rose	Choke cherry	Aspen	Choke cherry	Woods' rose
Dogwood	Aspen	Pin cherry	Aspen	Dogwood
Green ash	Pin cherry	Box-elder	Pin cherry	Green ash

**Table 3.** Species arrangement in the traditional buffer design.

Row 1	Row 2	Row 3	Row 4	Row 5
Caragana	Green ash	White Spruce	Green ash	Caragana
Caragana	Green ash	White Spruce	Green ash	Caragana
Caragana	Green ash	White Spruce	Green ash	Caragana
Caragana	Green ash	White Spruce	Green ash	Caragana
Caragana	Green ash	White Spruce	Green ash	Caragana
Caragana	Green ash	White Spruce	Green ash	Caragana
Caragana	Green ash	White Spruce	Green ash	Caragana
Caragana	Green ash	White Spruce	Green ash	Caragana
Caragana	Green ash	White Spruce	Green ash	Caragana
Caragana	Green ash	White Spruce	Green ash	Caragana
Caragana	Green ash	White Spruce	Green ash	Caragana
Caragana	Green ash	White Spruce	Green ash	Caragana

counted. In addition, ten green ash trees were measured in each treatment plot. Identity and percent cover of herbaceous species within a 1 m<sup>2</sup> (10.8 ft<sup>2</sup>) area in each treatment plot were determined in early August of the eight growing season by clipping above ground vegetation, separating according to species, then drying at 70°C for 72 hours to get dry weight of the plants.

Differences between height of green ash in the two designs were subjected to analysis of variance (GLM) with MINITAB<sup>®</sup> statistical software program (Release 14, Minitab, State College, Pennsylvania). Tukey's method was used to compare means (Chew 1976).

## Results

Wood's rose, choke cherry, and pin cherry showed strong development of multiple rhizome shoots in the Eco-Buffers (Table 4). There was no development of rhizome shoots for species used in the traditional design. Development of rhizome shoots in the Eco-Buffer resulted in a dense woody plant community in the understory and completely captured the buffer floor.

Tree and shrub height varied by species (Table 4). The tallest trees in the Eco-Buffer treatment were green ash followed by aspen. Green ash, which was common to both treatments, was significantly ( $P=0.01$ ) taller in the Eco-Buffer treatment when compared with ash trees in the traditional design (Table 4).

Weed populations were significantly greater in the traditional design ( $P=0.001$ ) than in the Eco-Buffer (Table 5). Weeds were predominantly perennial species, with brome grass making up over 50 percent of the herbaceous weed community. The principle factor influencing the structure of undergrowth is light. The open nature of the traditional design canopy allowed more light to penetrate the understory, consequently herbaceous weedy vegetation easily became dominant. The dense stratum of the Eco-Buffer design virtually eliminated opportunity for weed growth.

The main difference between the traditional design and the Eco-Buffer design was site capture and woody plant density (Table 6). This is due to extensive spreading of rhizome shoots by shrubs in the

**Table 4.** Growth characteristics of trees and shrubs in each buffer design (NP = not planted).

Species	Design Treatment			
	Eco-Buffer		Traditional	
	Height (cm)	Rhizome Shoots (no.)	Height (cm)	Rhizome Shoots (no.)
Woods' rose	136	98	NP	
Dogwood	167	0	NP	
Round-leaf hawthorn	309	0	NP	
Caragana	NP		243	0
Choke cherry	258	50	NP	
Pin cherry	305	116	NP	
Aspen	367	4	NP	
Green ash	415a	0	333b	0
Box-elder	336	0	NP	
White spruce	NP		130	0

**Table 5.** Herbaceous groundcover in design treatments.

Herbaceous Groundcover	Buffer Treatment	
	Eco-Buffer	Traditional
Total dry weight (g/m <sup>2</sup> )	2.7a	550.5b
Brome grass (%)		57.1
Canada thistle (%)		26.6
Perennial sow thistle (%)		16.3

**Table 6.** Plant density in buffer designs.

Design Treatment	2004 - Trees/Shrubs planted (stems/ha)	2011 - Trees/Shrubs present (stems/ha)
Eco-Buffer	5000	35000
Traditional	3500	3250

Eco-Buffer designs. After eight years, the Eco-Buffer design averaged 35,000 plants per hectare of buffer, an increase of 30,000 plants per hectare from the time of planting. On the other hand, the traditional design averaged 3250 plants per hectare, a decrease of 250 plants per hectare. The high density of plants in the Eco-Buffer did not affect growth or survival of the individual species.

## Summary

Eco-Buffers are structurally more complex than traditional, multi-row shelterbelt designs (Figure 1). These buffers provide superior habitat for birds, mammals, and pollinating insects. Spreading rhizome shoots of some species resulted in quick site capture in Eco-Buffers compared to a traditional buffer design, thereby eliminating the need for long-term weed control. Furthermore, the traditional shelterbelt design had a weed higher density than Eco-Buffers resulting in reduced tree growth.



**Figure 1.** Eco-Buffers, consisting of long-lived and short-lived trees along with small, medium and tall shrubs are structurally complex compared to traditional, multi-row shelterbelt designs.

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# Tamarisk Coalition — Native Riparian Plant Materials Program

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**Abstract:** The Tamarisk Coalition (TC), a nonprofit organization dedicated to riparian restoration in the western United States, has created a Native Plant Materials Program to address the identified need for native riparian plant species for use in revegetation efforts on the Colorado Plateau. The specific components of the Native Plant Materials Program include: 1) provide seed collection and riparian restoration training; 2) work with various partnerships and collaborators to help define needs/goals for active restoration; 3) help facilitate the development of appropriate replacement plant species for restoration; and 4) work with partners to develop a business model for the sustainable production of locally grown native plant materials. The TC has received numerous grants to assist with implementing this program. Grantors include the Central Utah Project Completion Act, Xcel Energy, Walton Family Foundation, and the Colorado Healthy Rivers Fund. Based on experiences resulting from implementing the Native Plant Materials Program and feedback received from multiple watershed organizations, native plant materials development for active restoration efforts remains an important, if not critical, need. TC continues to document its work and that of other organizations in an effort to help inform ongoing efforts.

**Keywords:** riparian, native plants, long-stem, pole planting, Colorado Plateau

## Background

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Tamarisk Coalition (TC), based in Grand Junction, CO, is a 501c(3) non-profit organization whose mission is to provide technical assistance and educational support for the restoration of riparian lands. As part of that mission, TC has been helping landowners and land managers meet their active restoration goals. TC's Native Plant Materials Program has been designed to address the identified need for native riverside plant species for use in revegetation efforts on the Colorado Plateau.

Several community-based watershed groups, located within western Colorado and eastern Utah, have been working towards the goal of watershed restoration, with an emphasis on the reestablishment of native species in areas currently occupied by tamarisk (*Tamarix* spp.) and Russian olive (*Elaeagnus angustifolia*). Current projects focus on the revegetation of areas where tamarisk and Russian olive have been actively removed or where tamarisk has been affected by the tamarisk leaf beetle (*Diorhabda elongata*), a biological control agent introduced to manage tamarisk.

While many areas may naturally regenerate, active revegetation is often necessary. The importance of using native plants in revegetation efforts has been emphasized in watershed restoration efforts (Sher and others 2010); supply of locally adapted, or ecotype-specific, plants that can be used with minimal post-planting maintenance, however, is currently limited. There are local nurseries that specialize in the production of native plants, yet many of these nurseries are not geared towards large-scale production of ecotype-specific plants in appropriate containers and/or growth forms for watershed restoration efforts.

Materials grown as long-stem transplants and outplanted using deep planting methods are especially useful in arid land revegetation efforts. Plants grown in this manner develop robust root systems capable of extending into the capillary fringe, that is, the permanent soil moisture above the water table. As a result, the need for post-planting irrigation is greatly reduced or eliminated. Revegetation success rates of 90% or more have been found in areas where these techniques have been used (Dreesen and Fenchel 2010).

Despite their proven utility, ecotype specific and long-stem plant materials are generally unavailable across the Colorado Plateau except at the Los Lunas Plant Material Center (LLPMC) in New Mexico. Land managers often use commercial non-adapted nursery stock, or they resort to transporting materials from the LLPMC.

Due to the identified need for suitable-sized cottonwood poles for revegetation efforts, TC is also coordinating the establishment of a cottonwood pole plantation in western Colorado. TC believes that it can, through the creation of this plantation, greatly reduce costs while simultaneously improving product supply for restoration practitioners. Once established, cottonwood poles can be sold at minimal cost to help generate maintenance funding as well as supplemental income for landowners.

Ultimately, TC envisions local nurseries sustainably growing native, long-stem products and cottonwood poles. From cursory research, there appears to be resistance and/or barriers to the adoption of these grow-out methods commercially. TC would like to further explore options for including commercial growers in restoration efforts. Given the anticipated need for materials in western Colorado alone, TC recognizes a niche that could profitably be filled by local entrepreneurs. TC has been working with the Upper Colorado Environmental Plant Center (UCEPC) to help further develop technologies that can subsequently be transferred to commercial growers.

The specific components of the Native Plant Materials Program include: 1) provide seed collection and riparian restoration training; 2) work with various partnerships and collaborators to help define needs/goals for active restoration; 3) help facilitate the development of appropriate replacement plant species for restoration; and 4) work with partners to develop a business model for the sustainable production of locally grown native plant materials. The TC has received numerous grants to assist with implementing this program. Grantors include the Central Utah Project Completion Act, Xcel Energy, Walton Family Foundation, and the Colorado Healthy Rivers Fund. The following program accomplishments are a result of activities conducted through these grant programs.

## Program Components and Accomplishments

### Seed Collection and Riparian Restoration Training

In partnership with UCEPC, LLPMC, Colorado State University, and Rim to Rim Restoration, the TC has hosted numerous training opportunities for land managers, private land owners, and other organizations. These trainings include topics such as seed collection, secondary weed control (focus on Russian knapweed [*Rhaponticum repens*]), long-stem and pole outplanting techniques, and native grass establishment methods. In 2010 and 2011, the TC coordinated training for over 120 land managers and private land owners in western Colorado and Utah. These trainings have helped to educate watershed partnership members currently engaged in restoration activities on successful planting methodologies.

### Partnerships and Collaborations to Define Needs/Goals for Active Restoration

TC staff members have been actively engaged with numerous watershed partnerships, including the Dolores River Restoration Partnership (DRRP), Escalante River Watershed Partnership (ERWP), Northwest Colorado Watershed Partnership (NWCP), and Southeast Utah Tamarisk Partnership (SEUTP). Through the DRRP and the

ERWP, TC is currently working to identify and plan for restoration needs in these watersheds. Staff has actively participated on committees tasked with shaping restoration goals; in many instances, TC staff has also taken leadership roles in the creation of restoration prioritization documents that identify species for development.

## Facilitate the Development of Appropriate Replacement Plant Species for Restoration

Although the need and importance of utilizing native plants in restoration has been expressed, the ability for land managers to actually obtain plant materials is a challenge. To address this, the TC is working to: 1) support development of ecotype-specific, long-stem products for restoration efforts on the Dolores and Escalante Rivers, including collecting or coordinating seed collection to support efforts; and 2) develop and maintain cottonwood plantation(s) along the Colorado River main stem in western Colorado with poles produced to be used in local restoration efforts.

### Long-Stem Production

UCEPC has begun propagation of several species from seeds collected by TC and other Colorado sources. Together, existing grant funds will support the development of 350 long-stem plants (Table 1). Plants should be available for restoration efforts in 2 to 3 years.

TC will facilitate the development of additional riparian species at local nurseries on the Colorado Plateau. The exact number of plants that will be made available is not yet known.

### Cottonwood Pole Plantation Development

Due to the identified need for suitable-sized cottonwood poles for revegetation efforts, TC is coordinating the establishment of

**Table 1.** Species identified for seed collection and propagation status.

Species	Collected by TC	Propagation Status
Box elder ( <i>Acer negundo</i> )	Yes; seed not viable	UCEPC to use White River Source; in production
Baccharis ( <i>Baccharis salicina</i> )	Yes; small quantities	In production
Single leaf ash ( <i>Fraxinus anomala</i> )	Yes**; seed not viable	NA
Skunkbush sumac ( <i>Rhus trilobata</i> )	Yes; also volunteer collection	In production
golden currant ( <i>Ribes aureum</i> )	No*; stock collected from UCEPC	In production
wax curran ( <i>Ribes cereum</i> )	No**; stock collected from UCEPC	In production
Woods' rose ( <i>Rosa woodsii</i> )	Yes, insufficient quantities; however, cuttings available	In production
silverleaf buffaloberry ( <i>Shepherdia argenta</i> )	No*; using UCEPC collection from Dolores	100 in long-stem production; 300 m (1000 ft) in bareroot production

\* Seed was not found locally on Colorado River; TC will be working with professional seed collectors to obtain these species in the future.

\*\* This species, while of interest to UCEPC, is not applicable for lower elevation riparian restoration sites. The species was taken off future seed collection lists.

a cottonwood pole plantation in Mack, CO. TC believes that it can, through the creation of this plantation, greatly reduce costs while simultaneously improving product supply for restoration practitioners. Once established, cottonwood poles can be sold at minimal cost to help generate maintenance funding as well as supplemental income for landowners. TC is growing seedlings from both cuttings and wildland-collected seeds. Nearly 1000 cottonwoods were planted in fall of 2011; an additional 5000 cottonwoods will be planted in the spring of 2012.

A private landowner has donated the use of his land, irrigation water, and labor to plant and maintain the plantation. The landowner will, in turn, sell mature cottonwood poles to land managers and others conducting restoration. Proceeds from the sale will support continued plantation operation and maintenance. Plantation stock can be cut approximately three times before replanting needs to occur.

### **Partnerships to Develop a Business Model for Sustainable Production of Locally-Grown Native Plant Materials**

TC has been working with a number of partners to further explore options for how the development and sale of native plant materials can be incentivized and ultimately become a profitable and sustainable endeavor. This continues to be an on-going effort that has been aided by conference participation and other networking opportunities. TC recently attended the Colorado Plateau Native Plant Initiative Annual Meeting (Moab, UT) and the National Native Seed Conference (Snowbird, UT), and TC is currently exploring collaborative opportunities with the Bureau of Land Management (BLM) and Uncompahgre Project.

### **Evaluation**

To date, grant opportunities from the Central Utah Completion Act, Xcel Energy, Walton Family Foundation, and Colorado Healthy Rivers Fund have enabled TC to host relevant and needed training on seed collection and riparian restoration techniques for agencies, non-profits,

and landowners in western Colorado and eastern Utah. Support was also provided to begin working towards the goal of providing native plant species for restoration efforts. These grant programs were critical in building additional backing to further program goals.

The TC learned a great deal over the last year about challenges to native seed collection and plant propagation and marketing by local nurseries. As part of current work, more emphasis is now being placed on identifying ways to enhance communication and collaboration between suppliers and users of native plant materials. TC is also exploring ways to strategically partner with other organizations with complementary goals, such as the Natural Resources Conservation Service, BLM, Colorado State Forest Service, and Rim to Rim Restoration in Moab, UT. The Colorado Plateau Native Plant Annual Meeting, held in Moab, UT in early March, was especially helpful in gaining a better understanding of how TC can complement efforts already underway by collaborators.

TC is also working to develop additional training modules, outreach materials, and Best Management Practices geared towards private landowners and other smaller organizations conducting riparian restoration.

Based on feedback received from multiple watershed organizations, native plant materials development for active restoration efforts remains an important, if not critical, need. TC continues to document its work and that of other organizations in an effort to help inform ongoing efforts. A recently developed strategic plan helps to guide these efforts and provides benchmarks for continued success.

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# Management Implications of Using Tree Shelters for Restoration of High Elevation Spruce-Fir Forests in the Rocky Mountains

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Jacobs DF. 2012. Management implications of using tree shelters for restoration of high elevation spruce-fir forests in the Rocky Mountains. In: Haase DL, Pinto JR, Riley LE, technical coordinators. National Proceedings: Forest and Conservation Nursery Associations—2011. Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. Proceedings RMRS-P-68. 79-81. Available at: [http://www.fs.fed.us/rm/pubs/rmrs\\_p068.html](http://www.fs.fed.us/rm/pubs/rmrs_p068.html)

**Abstract:** This paper presents a summary of a research project designed to study the use of tree shelters as a means to provide initial shade for planted Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) seedlings on a reforestation site in southwestern Colorado where several past planting attempts had failed. Study results following 2, 6, and 11 growing seasons were formally published elsewhere. Four different shelter colors providing various shading levels and a control, consisting of shading using debris within the site, were included when the study was initiated in 1996. The darkest shelter color was excluded after two years due to high mortality. Half of the shelters were removed in 2000 to examine seedling response to tree shelter removal. In 2007, control seedlings had lower survival (35%) than any other treatment (ranging from 59 to 78%). Shelter removal in the lightest two shelter color treatments did not reduce survival, suggesting that seedlings can grow in full sun after four years of shading. The lightest shelter color with shelters removed produced the best overall seedling development. This paper elaborates on site- and landscape-level management implications surrounding results of this research.

**Keywords:** Colorado, environmental impact, forest restoration, gopher browse, Englemann spruce, *Picea engelmannii*, tube shelters

## Introduction

This paper discusses site- and landscape-level management implications of a long-term study in the high elevation forests of southwestern Colorado (Figure 1) initiated to examine use of different colors of tree shelters (providing variable levels of shading) as a means to improve Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) reforestation success. A description of the project justification, study site (Figure 2), experimental methodology, and results following two growing seasons were presented in Jacobs and Steinbeck (2001). We found that use of lighter-colored tree shelters improved early growth and survival of planted seedlings as compared to the traditional method of relying upon natural shade within the site. This was attributed to decreased animal browse (i.e., gophers) of sheltered seedlings along with positive changes to seedling development associated with shelter microclimatic conditions (Oliet and Jacobs 2007). Seedling responses to subsequent tree shelter removal (vs. not) were then published after 6 (Jacobs 2004) and 11 (Jacobs 2001) growing seasons. Results indicated that control seedlings had lower survival (35%) than any other treatment (ranging from 59 to 78%). In the lightest 2 shelter color treatments, shelter removal did not reduce survival indicating that seedlings can grow in full sun after four years of shading. The best overall response (i.e., survival, absolute height, and root-collar diameter) occurred in the lightest shelter color with shelters removed.



**Figure 1.** High elevation Engelmann spruce-subalpine forest type in southwestern Colorado.



**Figure 2.** The Orphan Butte site located at an elevation of approximately 3273 m in the San Juan National Forest, Colorado. The entire 48-ha site was clearcut in 1971 and following failed natural regeneration, the site was planted in 1976, 1985, and 1996 in an effort to reach minimum stocking.

## Management Implications

This long-term project has produced encouraging results toward successful restoration of these high-elevation spruce-fir sites where past planting efforts have proven difficult (Figures 3 and 4). Results also help emphasize the importance of long-term monitoring of plantation experiments on harsh restoration sites before issuing management recommendations as results tend to shift over time (Oliet and others 2005). The best general responses after 11 growing seasons occurred in the lightest shelter color (with or without shelter removal) and the second lightest shelter (with shelter removal). Thus, a lighter color shelter (i.e., 24% PAR) is recommended in operation especially if the shelters may not be subsequently removed. Although seedlings without shelter removal in the lightest shelter color had excellent performance, shelter removal resulted in seedlings with significantly larger root-collar diameter. Additionally, growth restrictions for sheltered seedlings could still be observed in the future. Therefore, it is recommended that funding for shelter removal after four years be allocated on these restoration projects. Development of tree shelter design has advanced since the initiation of this study and more rigid models are now available that may allow relatively simple installation, removal, and reliable re-use at another site. This would provide further benefit in minimizing environmental contamination associated with discarded tree shelters. Finally, ability to re-use a tree shelter at multiple sites may help to reduce the cost of incorporating tree shelters into these restoration projects.



**Figure 3.** Sheltered Engelmann spruce following 11 growing seasons.



**Figure 4.** Study seedling beginning to produce reproductive cones after 11 growing seasons.



In addition to these stand-level management implications, it is interesting to ponder several larger, landscape-level issues related to this research. Efforts to salvage trees infected by the spruce bark beetle (*Dendroctonus rufipennis* Kirby) resulted in dramatic increases in harvesting in the high-elevation Rocky Mountain forests around 1950. Many of these clearcut sites remain poorly or partially stocked due to subsequent failure of both natural regeneration and plantings (Ronco and Noble 1971; Alexander 1987). Although the US Forest Service has continued with restoration plantings on these sites, the intensity of the program has fluctuated over time and generally declined in recent years partly due to a decline in general funds, especially those generated from timber sales. This brings forth a question regarding the fate of these understocked sites through various time scales (i.e., 100, 1,000, or 10,000 years). In the absence of planting, these sites will likely be invaded by natural regeneration of trees from surrounding stands but the timeframe required will depend on current stocking levels, seed availability, and site conditions. Hundreds of years may be required before full stocking is attained on some sites. Clearly this negatively affects the commercial potential of these sites and, simultaneously, the ecosystem and its ability to provide wildlife habitat, watershed protection, and carbon sequestration is impacted by conversion of these mature forests to non-stocked forestlands. In some cases, the US Forest Service is considering modifying land use designations to re-classify some of these clearcut sites as meadows. Some may argue that conversion of some forest sites to meadow via clearcutting has negligible impacts on these ecosystems at the landscape scale. Nevertheless, the US Forest Service must decide if they have a moral obligation to the public to ensure that these harvested sites are reforested.

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# Genetic and Environmental Influences on Cold Hardiness of Native and Introduced Riparian Trees

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Friedman JM, Roelle JE, Cade BS. 2012. Genetic and environmental influences on cold hardiness of native and introduced riparian trees. In: Haase DL, Pinto JR, Riley LE, technical coordinators. National Proceedings: Forest and Conservation Nursery Associations—2011. Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. Proceedings RMRS-P-68. 82-85. Available at: [http://www.fs.fed.us/rm/pubs/rmrs\\_p068.html](http://www.fs.fed.us/rm/pubs/rmrs_p068.html)

**Abstract:** To explore latitudinal genetic variation in cold hardiness and leaf phenology, we planted a common garden of paired collections of native and introduced riparian trees sampled along a latitudinal gradient. The garden in Fort Collins, Colorado (latitude 40.6°N), included 681 native plains cottonwood (*Populus deltoides* subsp. *monilifera*) and introduced saltcedar (*Tamarix ramosissima*, *T. chinensis*, and hybrids) collected from 15 sites from 29.2 to 47.6°N in the central United States. In the common garden, both species showed latitudinal variation in fall, but not spring, leaf phenology. This suggests that latitudinal gradient field observations in fall phenology are a result, at least in part, of the inherited variation in the critical photoperiod. Conversely, the latitudinal gradient field observations in spring phenology are largely a plastic response to the temperature gradient. Populations from higher latitudes exhibited earlier bud set and leaf senescence. Cold hardiness varied latitudinally in both fall and spring for both species. Although cottonwood was harder than saltcedar in midwinter, the reverse was true in late fall and early spring. The latitudinal variation in fall phenology and cold hardiness of saltcedar appears to have developed as a result of multiple introductions of genetically distinct populations, hybridization, and natural selection in the 150 years since introduction.

**Keywords:** Cold hardiness, latitude, phenology, *Populus deltoides*, rapid evolution, *Tamarix*

## Introduction

Because of the latitudinal gradient in temperature, wide-ranging species often display latitudinal gradients in phenology. Increasing latitude is typically associated with later leaf flush and flowering and earlier growth cessation, leaf senescence, and onset of cold hardiness (Sakai 1970, Ying and Bagley 1976). Latitudinal gradients in phenology reflect both genetic variation and a plastic response to the climatic gradient, and common-garden studies can be used to determine the relative importance of these factors (Colautti and others 2009). If phenological variation persists when plants from different latitudes are grown together, then the variation observed in the wild has a genetic component.

We examined phenology and cold hardiness in a common garden consisting of paired collections of a native and an introduced species. The selected species were cottonwood and saltcedar, riparian pioneer trees that compete for dominance along rivers throughout most of the western United States (Friedman and others 2005). Plains cottonwood (*Populus deltoides* Bartram ex Marsh. ssp. *monilifera* (Aiton) Eckenwalder) is the dominant riparian tree of the western Great Plains, ranging from northern Texas to southern Manitoba, Saskatchewan, and Alberta at latitude 30–55°N and longitude 96–114°W (USDA 2009). Riparian shrubs of the genus *Tamarix* were introduced to North America in the mid-1800s as ornamental plants and for erosion control. Although there are now several *Tamarix* species in the United States, *T. chinensis* Lour. and *T. ramosissima* Ledeb. are by far the most abundant (Gaskin and Kazmer 2009). Although these two species are morphologically and genetically distinct in Asia, the North American population is dominated by their hybrids (Friedman and others 2008, Gaskin and Kazmer 2009). We refer to the complex of *T. ramosissima*, *T. chinensis*, and their hybrids as saltcedar. Saltcedar is now the second most abundant riparian woody plant in the interior western United States (Friedman and others 2005).

A comparison of latitudinal gradients in cold hardiness and phenology in cottonwood and saltcedar is valuable for two reasons. First, it makes it possible to explore whether differences in cold hardiness could explain the apparent inferior competitive ability of saltcedar in the north. This information would help to assess the potential for spread of this major invasive species both in the present climate and in response to climate warming. Second, comparing latitudinal variation in the native and introduced species explores whether patterns of clinal variation typical of native species can rapidly evolve in introduced species.

## Materials and Methods

In February and March of 2005, we collected plains cottonwood and saltcedar as cuttings from 15 sites distributed along a latitudinal gradient from 29.2 to 47.6°N in the central U.S. (Friedman and others 2008, 2011). On 16 August 2005, we planted rooted cuttings in a common garden at the Colorado State Nursery in Fort Collins at latitude 40.58°N and longitude 105.14°W. The garden contained 313 cottonwoods and 368 saltcedars planted in a clay loam soil in a random design.

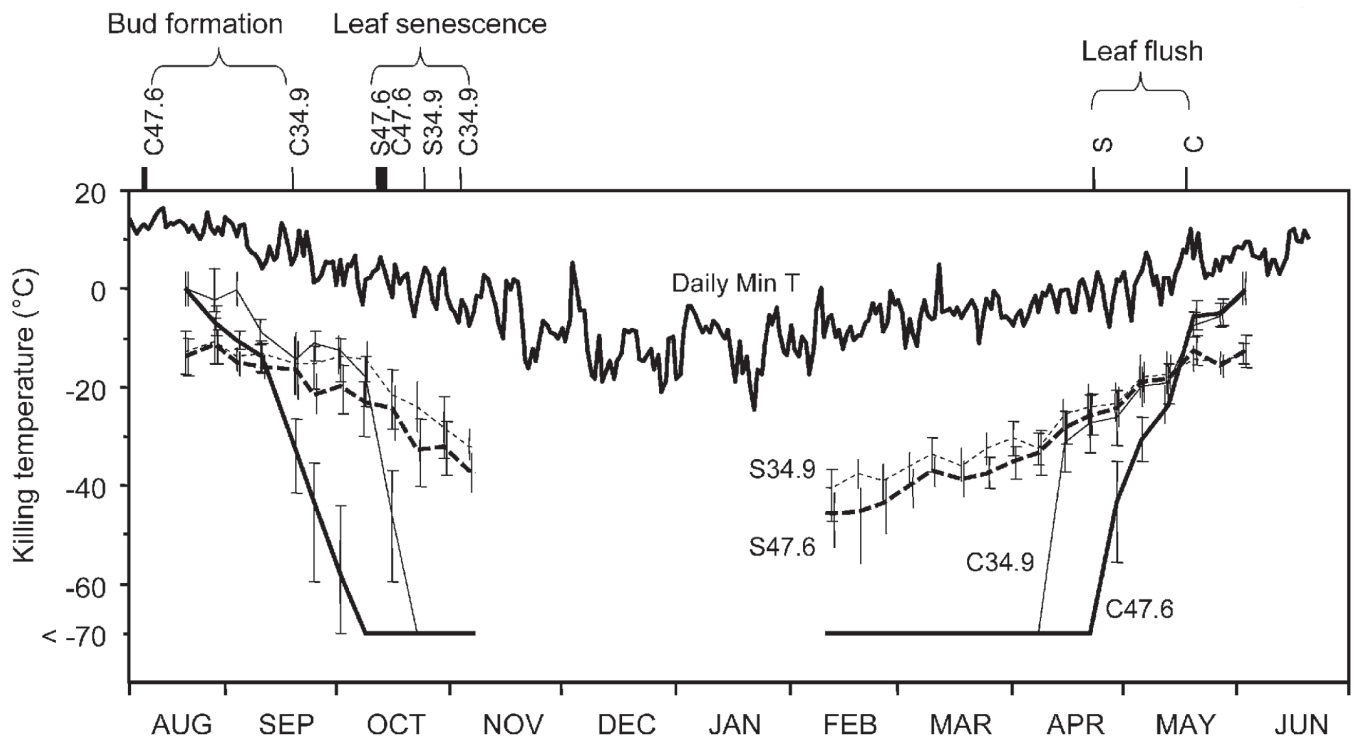
In 2006, 2007, and 2008, a single observer made weekly phenological observations of plants in the common garden. We observed the dates of leaf flush and leaf senescence of both species and the date of terminal bud formation in cottonwood. We measured variation in cold hardiness of plant stems through time, within populations, between latitudes, and between species. To measure cold hardiness we cut a 40-cm twig into seven 5-cm pieces, placed the pieces in wire racks, and exposed them to seven different temperatures using a programmable temperature chamber. Post freezing, the stems were placed on racks in water at room temperature, incubated for two weeks, and then scored as live or dead (Calkins and Swanson 1990). We defined the killing temperature (LT50) as the temperature at which the probability of dying exceeded 0.50 and used logistic regression in SAS<sup>®</sup> (SAS Institute, Inc., Cary, NC) to estimate probability of dying as a function of temperature, latitude of origin, and species. A more detailed presentation of methods and results can be found in Friedman and others (2011).

## Results

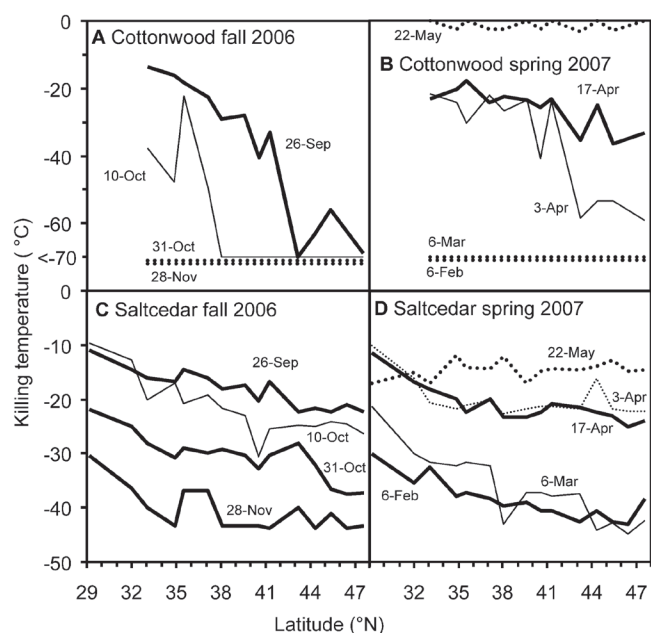
The timing of cottonwood terminal bud formation was strongly negatively correlated with latitude. Northern cottonwoods formed their terminal buds and ceased extension growth before southern cottonwoods (Figure 1). In the years 2006, 2007, and 2008, cottonwoods from latitude 47.6 formed buds 20 days, 37 days, and 23 days before cottonwoods from latitude 34.9, and the correlations between bud formation date and latitude were -0.66, -0.84 and -0.73.

The timing of leaf senescence for both species was also negatively correlated with latitude (Figure 1). Consistent with the latitudinal effect on bud formation, leaves of northern individuals of both species became senescent before those of southern individuals (Figure 1). The time difference between leaf senescence at latitudes 34.9 and 47.6°N was larger in cottonwood (21 days) than in saltcedar (10 days) and the correlation between latitude and leaf senescence date was stronger in cottonwood (-0.58) than in saltcedar (-0.37) (Figure 2). The timing of spring leaf flush was not correlated with latitude in cottonwood and weakly and inconsistently correlated with latitude in saltcedar. Leaf flush occurred earlier in saltcedar than in cottonwood by 22 days in 2007, and 21 days in 2008 (Figure 1).

Stems of both cottonwood and saltcedar survived colder temperatures in winter than in summer, but this seasonal cycle was stronger in cottonwood than in saltcedar (Figures 1 and 2); as a result cottonwood was harder in midwinter, but saltcedar was harder in the late spring and early fall. In autumn, killing temperatures



**Figure 1.** Temporal variation in killing temperature for twigs of northern and southern plains cottonwood (C) and saltcedar (S) grown in Fort Collins, Colorado (latitude 40.6°N) during fall 2007 and spring 2008. Northern individuals are from Fort Peck Reservoir, Montana, latitude 47.6°N and southern individuals are from Buffalo Lake National Wildlife Refuge, Texas, latitude 34.9°N. Mean values by species and latitude for timing of leaf flush, bud formation and leaf senescence are shown above the graph. Daily minimum temperature data are from the Christman Field Weather Station (Colorado Climate Center) about 1 km from the common garden.



**Figure 2.** Latitudinal variation in killing temperature for twigs of plains cottonwood during (A) fall 2006 and (B) spring 2007, and saltcedar during (C) fall 2006 and (D) spring 2007. Each line represents data collected on a single date. Solid lines indicate that the effect of latitude was significant at the 0.05 level in multiple logistic regression (dotted lines are not significant). Line and dot thickness are varied arbitrarily for clarity. Plant collection locations are shown in Friedman et al. (2008).

for saltcedar gradually decreased, reaching a minimum in mid-winter. Saltcedar from latitudes 34.9 and 47.6°N survived temperatures of -41°C and -46°C on 12 February 2008. In contrast, killing temperatures decreased precipitously for cottonwood. By mid-October 2007 cottonwood from both 34.9 and 47.6°N latitude survived -70°C, the coldest temperature attainable in our temperature chamber. Temperatures of -70°C or warmer did not kill cottonwood again until April 2008 (Figure 1).

Both cottonwood and saltcedar demonstrated inherited latitudinal variation in cold hardiness (Figure 2). In saltcedar, northern populations survived colder temperatures than southern populations throughout the cold season (Figure 2, C & D). The difference in killing temperature for the extreme latitudes on the gradient (29.2 and 47.6°N) reached a maximum of 15 to 20°C in the spring and fall and decreased to about 10°C in mid-winter (Figure 2, C & D). For cottonwood the latitudinal effect was manifested as a difference in the timing of a critical threshold in fall and spring. Cottonwoods from all latitudes had similar killing temperatures in the summer, underwent a period of rapid cold hardening, and by mid-winter could survive temperatures colder than any that occur in the study region.

## Discussion

Although cottonwood is extremely cold hardy in mid-winter, it is less hardy than saltcedar in the late spring and late summer. Leaf flush in cottonwood coincided with a sharp decrease in cold hardiness. This sensitivity to cold in spring may explain the late leaf flush of cottonwood relative to saltcedar. Plains cottonwood leaf buds from several sites across Nebraska opened after those of three other dominant trees in the western Great Plains, *Ulmus americana*, *Fraxinus pennsylvanica*, and *Acer negundo*, and at the same time as those of *Quercus macrocarpa* (McMillan 1957). Therefore, although cottonwood is extremely hardy in mid-winter, sensitivity to cold after

leaf flush limits the growing season for this species.

As predicted, we found strong inherited variation in fall, but not spring, leaf phenology of cottonwood as a function of latitude of origin (Pauley and Perry 1954, Ying and Bagley 1976). In the field, between latitudes 34.9 and 47.6°N, the date of leaf flush of *Populus deltoides* is delayed by about 44 days and the date of growth cessation is advanced by about 32 days (Kaszakiewicz and Fogg 1967). In our common garden, comparing cottonwood populations from latitudes 34.9 and 47.6°N, leaf flush was unaffected by latitude and the date of growth cessation was advanced by an average of 27 days. These results support the hypothesis that the latitudinal variation in fall phenology observed in the field has a strong genetic component related in part to variation in the critical photoperiod for growth cessation, while the latitudinal variation observed in the field in spring phenology is largely a plastic response to the temperature gradient (Friedman and others 2011).

In spite of its recent introduction to North America, saltcedar showed latitudinal variation in the timing of leaf senescence and cold hardiness from fall through spring. Furthermore, growth chamber experiments comparing northern and southern saltcedar have demonstrated inherited temperature-dependent differences in root-shoot ratio (Sexton and others 2002). This latitudinal genetic variation appears to have resulted from (1) multiple introductions of genetically distinct populations, including *T. chinensis* in the south and *T. ramosissima* in the north (Gaskin and Kazmer 2009); (2) hybridization that produced a population containing extensive genetic variation for leaf phenology and cold hardiness (Friedman and others 2008); and (3) natural selection. The hypothesis that the observed latitudinal gradient in North America resulted, at least in part, from natural selection after introduction is supported by the fact that North American *Tamarix* are genetically distinct from Eurasian *Tamarix* (Gaskin and Kazmer 2009).

## Summary

In mid-winter, all plains cottonwoods survived colder temperatures than occur in the range of this species, suggesting that exposure to extreme cold in mid-winter is not an important mortality factor. In contrast, saltcedar, even when completely hardened off, was killed by temperatures around -40°C, which is within the temperature range of the northern Great Plains. We conclude that winter cold is a significant factor influencing distribution of saltcedar in the U.S. Increases in winter low temperatures could promote northward spread of saltcedar in the future.

Whereas leaf phenology in our common garden varied with latitude of origin in fall but not spring, cold hardiness of cottonwood and saltcedar twigs varied with latitude of origin in both fall and spring. For a given latitude, the onset of cottonwood cold hardiness occurred after growth cessation and before leaf senescence, and there was strong correlation among growth cessation, leaf senescence, and fall cold hardiness within and between years.

Global increases in temperature could promote earlier leaf flush in spring and later growth cessation and leaf senescence in fall. Our results suggest that cottonwood and saltcedar can accomplish earlier leaf flush through plasticity. To the extent that growth cessation is controlled by photoperiod, however, development of later growth cessation will involve migration and natural selection. The development of a phenological cline in introduced saltcedar is evidence that such change can occur in a shrub population within 150 years.

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# Biology and Control of Eriophyid Mites with a Case Study of *Aceria* spp. on New Mexico Olive (*Forestiera pubescens* Nutt. var. *pubescens*)

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**Abstract:** The biology, recognition, and impact of eriophyid mites (with emphasis on species associated with trees and shrubs) are briefly reviewed. A case study of a leaf-curling eriophyid mite (*Aceria* sp.) attacking New Mexico olive (*Forestiera pubescens* Nutt. var. *pubescens*) is used to illustrate the complexities of developing control strategies for eriophyids in native plant nurseries. The effect of different acaricide treatments at various spray intervals are reported

**Keywords:** native plants, leaf-galls, acaricide timing, spray intervals

## Introduction

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The family Eriophyidae comprises some 85% of the superfamily Eriophyoidea that, in turn, includes approximately 4000 described species (de Lillo and Skoracka 2010). The Eriophyoidea also includes the Phytoptidae (found mainly on conifers and monocotyledons) and the Diptilomiopidae. The eriophyids are minute mites—less than 1 mm long (generally in the order of 0.1 to 0.2 mm), with 2 pairs of legs immediately behind the head. The body is elongated and annulated, and variously described as wedge-, cigar-, or carrot-shaped. A ventral ‘sucker’ is present at the caudal end and is used to attach the mite to the substrate during feeding, molting, and so on. The short, piercing mouthparts of these mites limits their feeding activities to the epidermal cells of their host plants.

The Eriophyoid mites are characterized by their high degree of host-specificity. According to a recent estimate, 80% have been reported in association with a single host species, 95% from a single host genus, and 99% from a single host family, a characteristic that has resulted in some species being used for the biological control of weed species (Skoracka and others 2010). It has been stated that there is probably at least 1 eriophyid mite associated with most plant species (Castagnoli and others 2010), but they often go unremarked because of their small size and the fact that many species have no noticeable impact on their hosts. Eriophyid mites tend to be associated with perennial plants, and some trees (including species of *Acer*, *Alnus*, *Fagus*, *Juglans*, *Olea*, *Prunus*, *Salix*, and *Carpinus*) host more than 10 associated species of eriophyids (Castagnoli and others 2010).

The best-studied eriophyids are pest species that cause various types of growth abnormalities in their host plants that are sometimes mistaken for disease symptoms. These abnormalities include:

russetting of leaves; shortening and russetting of shoots; the production of erineae (patches of dense, felty hairs on the leaf surface that act as refugia for the mites); or characteristic galls on leaves, buds, flowers, or stems. The latter may take the form of blisters, pouches, or leaf rolls that may affect the entire leaf margin, or just part of it (Westphal and Manson 1996). Feeding by a single female may be enough to initiate gall formation. In some cases, toxemias are induced that result in chlorotic or dead areas on leaves that can resemble “mosaic” diseases (Oldfield 1996). In addition to these direct effects on plant growth, a few eriophyids have been shown to act as vectors of plant viruses (for example, wheat streak mosaic virus). Although the eriophyids are not typically considered forest pests, they may be troublesome in nursery environments and urban settings.

Eriophyid mites often have variable and complex lifecycles. In the simplest case, eggs are laid on leaves or in buds and hatch into a larval stage that subsequently molts to a nymph, and later to an adult; a quiescent or resting stage typically precedes the 2 molts. The adult sex ratio is often biased towards females (up to 95% in some cases). Sperm transfer is indirect, with males surrounding newly eclosed adult females with spermatophores deposited on the leaf surface (up to 600 per male). In some species, unfertilized eggs develop into males. Females start producing eggs (approximately 50 each) within 1 to 7 days of emergence and live for approximately 1 month; therefore, it is possible for 6 to 8 generations per year under optimal conditions. In some species, 2 types of females are found: protogynes, the primary summer form; and deutogynes, an over-wintering form produced in response to seasonal cues such as leaf-hardening, cooling temperatures, and so on. These females overwinter in bark crevices, under bud-scales, and in similar protected sites. They may be inseminated prior to entering their over-wintering state, but generally will not lay eggs until the following spring (Manson and Oldfield 1996).

Most eriophyids are associated with perennial hosts on which populations persist from year to year, but summer generations of eriophyids may be dispersed by wind, phoretically by various animals, or through human activities. Wind dispersal has been recorded only in adults (mainly protogynes) and involves active movement to the edge of the leaf, orientation into the wind, and the adoption of a vertical stance supported by the caudal sucker; in some species, dense, vertical "chains" of adults have been observed orientated in this way. The same stance is adopted in relation to phoresy; the mites will attach themselves to the legs of insects such as aphids and bees and reach new plants in this way (Sabelis and Bruin 1996).

Natural enemies associated with eriophyids include predatory mites from various families (including Phytoseiidae and Stigmaeidae), the larval stage of certain hoverflies (family Syrphidae) and predatory midges (family Cecidomyiidae), predatory hemipterans (family Anthracoridae), and some species of coccinellid beetles (Perring and McMurtry 1996). Fungal pathogens have also been reported. Incorporating naturally occurring biological control agents into an integrated control strategy, however, remains something of a challenge given that eriophyids can cause plant growth distortion at very low population densities, and that such abnormalities can persist even in the absence of live mites. Producers of native trees and shrubs may also have the additional difficulty of dealing with undescribed eriophyid species whose biology, lifecycle, and phenology may be completely unknown. This is the case with an eriophyid leaf-curling mite (recently identified as an undescribed species of *Aceria*) that can have severe impacts on the growth of New Mexico olive (*Forestiera pubescens* Nuttall var. *pubescens*) in nursery and landscape settings in the southwestern US. Once infected, individual trees generally retain populations of the mite from year to year, suggesting that it overwinters under the bud scales. Symptoms of leaf curl appear about 3 to 4 weeks after bud-break, and the growth of affected trees can be severely impacted. The entire margin of affected leaves curls inward on the underside of the leaf, forming a tight seal against the edge of the petiole; the mites feed and reproduce within this protected habitat, making it hard to reach them with non-systemic pesticides. A series of acaricide trials has been conducted in New Mexico over the past 2 years with the objectives of identifying effective products and determining optimal spray timing for control of this pest.

## Materials and Methods

### Initial Field Trial

In 2009, an initial experiment was conducted to determine the effect of a single spray applied approximately 1 month after budbreak. The experimental trees were 1-year old field-grown specimens that were all infested during the previous season. Mite numbers were assessed prior to treatment by collecting 4 leaves from each of 16 trees, opening the rolled margin under a dissecting microscope, and counting the mites within. These pre-treatment counts were then used as a blocking factor in assigning four treatments with 4 replicates. The treatments were: 1) water alone (control); 2) Carbar-yl (Sevin®; Bayer CropScience, Research Triangle Park, NC) at a rate of 11.5 ml/l (1.5 oz/gal); 3) Lilly Miller Vegol™ Year Round (Walnut Creek, CA) pesticidal oil at a rate of 21 ml/l water (2 oz/3 qts water); and 4) the fungal pathogen *Beauveria bassiana* (Naturalis L®; Troy Biosciences Incorporated, Phoenix, AZ) at a rate of 3.9 ml/l (0.5 oz/gal). All treatments were applied to run-off with a hand-held sprayer. Mite counts were made 7 days after treatment as described above. Since the data were not normally distributed, they were analyzed by Kruskal-Wallis non-parametric ANOVA followed by Mann-Whitney comparisons between pairs of treatments using Minitab® statistical software.

### Spray Interval Trial

Use of a single spray approximately 1 month after budbreak was insufficient to provide acceptable control for the whole season; therefore, a second trial was conducted in 2011 to determine the optimum interval between successive sprays. The same experimental trees were used as described above, and 2 products were tested: Lilly Miller Vegol™ Year Round pesticidal oil at a rate of 21 ml/l water (2 oz/3 qts water) and SucraShield™ (a sucrose ester; Natural Forces, LLC, Davidson, NC) at a rate of 7.8 ml/l water (1 oz/gal). Vegol™ was applied at intervals of 1, 2, 3, or 4 weeks and the SucraShield™ at 3-week intervals. An untreated control was also included. Treatments commenced on 22 April, when mite numbers on the experimental trees averaged 0 to 1 per leaf, and were continued for the rest of the growing season. Each treatment was replicated 5 times in a randomized complete block design, with tree height as the blocking factor. Results were assessed every 4 weeks by determining the percentage of infested leaves on each of 6 randomly-selected shoots per tree. Data were analyzed as described above.

### Acaricide Trial with Container-Grown Trees

An additional trial was conducted in 2011 to assess the efficacy of seven additional products when applied to 1-year old potted trees (approximately 80 cm [31.5 in] high). Pre-treatment mite counts were based on samples of 3 leaves per tree, and infestation level was used as the blocking factor in a randomized complete block design with 7 replicates. The treatments were as follows:

Two applications at 7-day intervals:

Avid® (Abamectin; Syngenta Crop Protection Incorporated, Greensboro, NC) + 1% horticultural oil (62.5 ml/100 l [8 oz/100 gal])

Proclaim® (Emamectin benzoate; Syngenta Crop Protection Incorporated, Greensboro, NC) (31 and 62.5 ml/100 l [4 and 8 oz/100 gal])

Two applications at 14-day interval:

Kontos™ (Spirotetramat; OHP Incorporated; Mainland, PA) (26.5 ml/100 l [3.4 oz/100 gal])

Ultiflora™ (Milbemectin; Gowan Company, Yuma, AZ) (125 ml/100 l [16 oz/100 gal])

Akari® (Fenpyroximate; SePRO Corporation; Carmel, IN) (187.5 ml/100 l [24 oz/100 gal])

Single application:

Magus™ (Fenazaquin; Gowan Company, Yuma, AZ) (187.5 ml/100 l [24 oz/100 gal])

Hexygon® (Hexythiazox; Gowan Company, Yuma, AZ) (15.5 ml/100 l [2 oz/100 gal])

An untreated control was also included.

All treatments were applied to runoff with a hand-held sprayer. Post-treatment mite counts (from 3 leaves per tree) were made every week for 5 weeks following the initial applications and data were analyzed as described above.

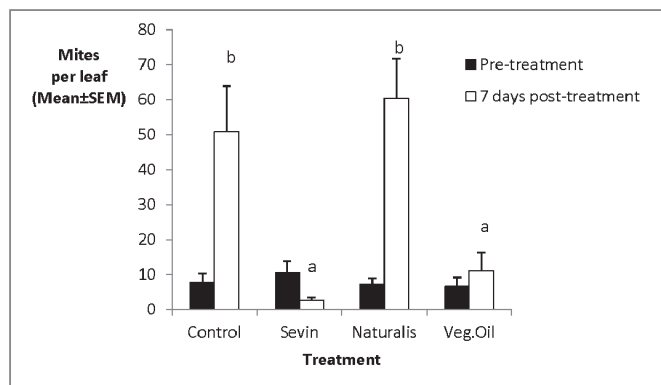
## Results and Discussion

### Initial Field Trial

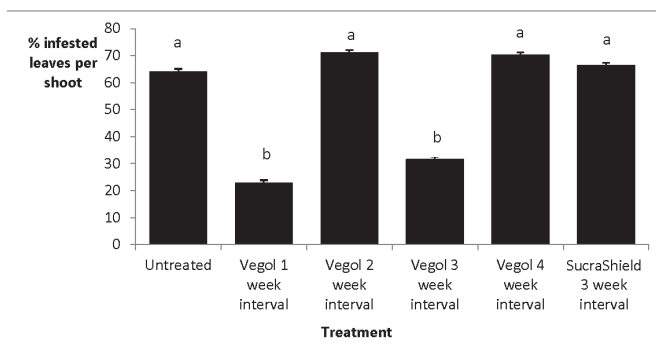
Sevin® and Vegol™ provided comparable levels of control when assessed 7 days after treatment; mite populations in the Naturalis L® treatment were not significantly different from those in the untreated control (Figure 1).

### Spray Interval Trial

The first evidence of leaf curling in the experimental trees was observed 4 weeks after treatment commenced. After 8, 12, and 20 weeks, only Vegol™ applied at either 1- or 3-week intervals significantly reduced the percentage of infested leaves per shoot compared to untreated controls. The results after 8 weeks are shown in Figure 2. The values for each treatment were very similar 12 weeks after the start of the trial; at the end of the experiment (after 20 weeks), all treatments showed a slight increase in mean percentage of infested leaves per shoot. In 2011, the growing season was unusually dry with no significant rainfall for the duration of the trial. As a result, there was an appreciable buildup of residue on the oil-treated trees (particularly those sprayed every week) that eventually led to some



**Figure 1.** Results of a single application of various pesticides to *Aceria* spp. on New Mexico olive approximately 1 month after bud break. Treatments with the same letter were not significantly different 7 days after treatment (Mann-Whitney test,  $P > 0.05$ ).

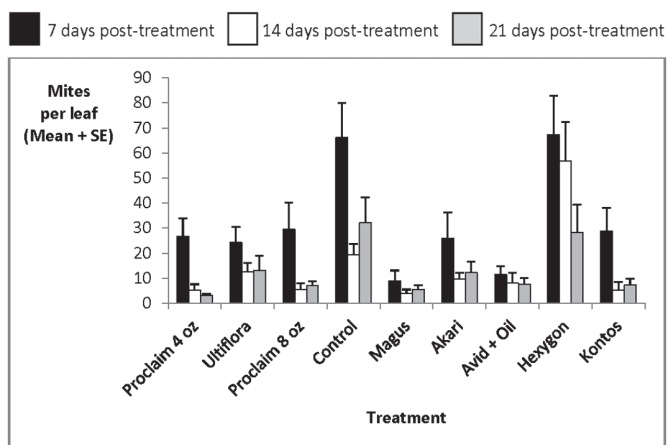


**Figure 2.** Effect of 2 pesticides applied at various spray intervals on *Aceria* spp. on field-grown New Mexico olive. The results shown are for 8 weeks after the start of the trial; those after 12 weeks are very similar. Treatments with the same letter are not significantly different (Mann-Whitney test,  $P > 0.05$ ).

phytotoxicity. Weekly spraying in any case is not very practical for commercial growers or landowners. A spray interval of 3 weeks gave comparable results, presumably because this interval corresponded with an initial knockdown of the mites as they emerged from overwintering. Correctly timing the onset of spraying is thus probably critical to developing robust treatment guidelines, and will be addressed in future studies.

### Acaricide Trial with Container-Grown Trees

The results of the acaricide trials up to 21 days after the initial treatments are shown in Figure 3. All treatments except Hexygon® gave comparable levels of control 14 and 21 days post-treatment, with Magus™ providing control comparable to the industry standard (Avid® + 1% horticultural oil) at 7 days post-treatment. Infestation levels in the untreated controls declined over the experimental period due to the activities of a predatory cecidomyiid midge and a predatory mite, but eriophyid populations in most treatments started to increase 5 weeks after the first applications were made. In all but the untreated controls, some uninfested new growth was apparent within 2 weeks of the first spray application, but not from apical meristems, which seemed to have been suppressed; all new growth was from lateral buds.



**Figure 3.** Effects of various acaricide treatments on *Aceria* spp. on container-grown New Mexico olive trees (up to 3 weeks after initial application).



Taken together, the results of these 3 trials indicate the importance of: 1) the correct timing at which to commence chemical control; and 2) the correct interval at which to repeat applications. The latter will depend on the nature and properties of the product selected. Even if suppression of mite populations is achieved, however, irreversible effects on plant growth may remain, and achieving acceptable control of species whose biology is largely unknown can be a significant challenge.

## Summary

The biology and recognition of eriophyid mites are reviewed. Developing control strategies for species whose biology and phenology are often unknown presents significant challenges that can only be overcome with thorough field experimentation.

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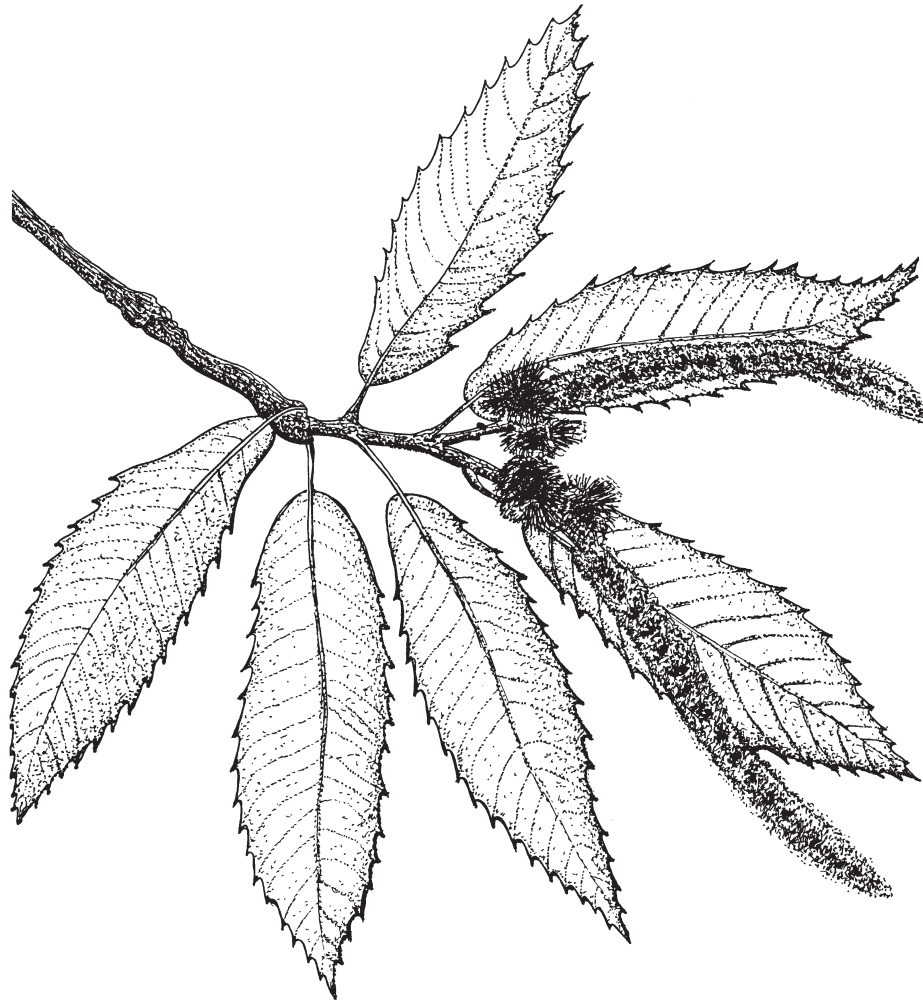
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# Intertribal Nursery Council Meeting

Temecula, California

September 12 to 15, 2011



Intertribal Nursery Council Meeting

*American chestnut drawing by Steven Morrison, College of Natural Resources, University of Idaho*

# Improving Germination of Red Elm (*Ulmus rubra*), Gray Alder (*Alnus incana*) and Buffaloberry (*Shepherdia canadensis*) Seeds with Gibberellic Acid

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Morales B, Barden C, Boyer C, Griffin J, Fisher L, Thompson J. 2012. Improving germination of red elm (*Ulmus rubra*), gray alder (*Alnus incana*) and buffaloberry (*Shepherdia canadensis*) seeds with gibberellic acid. In: Haase DL, Pinto JR, Riley LE, technical coordinators. National Proceedings: Forest and Conservation Nursery Associations—2011. Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. Proceedings RMRS-P-68. 93-95. Available at: [http://www.fs.fed.us/rm/pubs/rmrs\\_p068.html](http://www.fs.fed.us/rm/pubs/rmrs_p068.html)

**Abstract:** Red elm (*Ulmus rubra*), gray alder (*Alnus incana*), and buffaloberry (*Shepherdia canadensis*) are considered important plants for many Native American tribes in the United States. Native Americans use these 3 species for a variety of traditional and medicinal purposes. For example, red elm is still the preferred firewood for the cultural ceremonies of several tribes. Kansas tribal leaders would like to plant more of these species on tribal land, but they have been difficult to germinate due to seed dormancy mechanisms. While red elm is valued as a ceremonial tree, it is susceptible to Dutch Elm Disease (*Ophiostoma ulmi*), and it is not widely grown in ornamental nurseries. This has led to declining natural tree populations and difficulties in commercial propagation. The objective of this study was to evaluate techniques to promote germination of red elm, gray alder, and buffaloberry seeds, with the long-term goal to improve the production of these plants commercially and enable tribes and land owners to increase the presence of these native plants on their lands. Studies were conducted with stratified and non-stratified red elm, gray alder, and buffaloberry seeds soaked in 1 of 4 treatments: 0, 250, 500 or 1000 ppm of gibberellic acid (GA3). Results indicate the use of gibberellic acid in high concentrations is effective with non-stratified seeds of red elm.

**Keywords:** Native American, propagation, cultural plants, medicinal plants

## Introduction

Red elm (*Ulmus rubra*), also called slippery elm, is a native North American tree that is valued by many American Indian tribes as fuel for ceremonial fires at pow wows, funerals, or sweat lodges. Other past uses of red elm included the inner bark for cordage, fiber bags, and storage baskets. In spring, the cambium becomes very mucilaginous and has several medicinal uses including treatment for swollen glands, use for sore throats, and as an eyewash for sore eyes; women also drink a tea of the bark to make childbirth easier (USDA 2011a). Currently, tribes primarily use red elm for firewood in traditional ceremonies.

Gray alder (*Alnus incana*), also called tag alder, mountain alder, or hazel alder, is a species of moist lowlands, common in the region surrounding the Great Lakes including east-central Canada, Virginia, and Maryland. It is used locally for fuel and also supports symbiotic nitrogen-fixing bacteria in root nodules, which makes the alder valuable for improving soil fertility. Native Americans used alder to treat anemia, internal bleeding, urinary problems, bruises, backaches, and skin irritations (USDA 2011b). Alders are also used as landscape ornamentals.

Buffaloberry (*Shepherdia canadensis*) is also called soapberry, russet red buffaloberry, or Canadian buffaloberry. It is a native, deciduous, nitrogen-fixing shrub with broad distribution ranging from Alaska to Maine, south from New York to South Dakota, and south at higher elevations into Arizona. Buffaloberry fruits are eaten fresh or dried and also used to make “Indian ice cream”. Berry juice is used to prevent heart attacks and indigestion. The berries are also chewed to induce childbirth (USDA 2011c).

Gibberellic acid (GA<sub>3</sub>) is a naturally occurring plant hormone that can release seeds from dormancy. The positive effect of GA<sub>3</sub> promotes uniform seed germination and increases germination percentages (Adams et al., 2010). Gibberellic acid removes physiological dormancy mechanisms that often require lengthy stratification or light to maximize germination (Norden et al., 2007). Seeds of red elm, gray alder, and buffaloberry exhibit unknown dormancy issues and thus are the subject of this investigation. Specifically, this study evaluates the use of stratification and GA<sub>3</sub> to promote germination of red elm, gray alder, and buffaloberry seeds, with the long-term goal to improve the production of these plants commercially and enable tribes and land owners to increase the presence of these native plants on their lands.

## Materials and Methods

Red elm (*Ulmus rubra*), gray alder (*Alnus incana*), and buffaloberry (*Shepherdia canadensis*) seeds were used for this study. In April 2010, red elm seeds were collected from 2 Kansas locations: Butler and Douglas Counties. Gray alder and buffaloberry seeds were obtained from Lawyers Nursery of Montana.

The experimental design for each species was a randomized complete block with a 2 × 4 arrangement of factorial treatments. The factorial design included 2 stratification treatments (no stratification or stratification) and 4 gibberellic acid (GA<sub>3</sub>) treatments (0, 250, 500, 1000 ppm). The experiment was replicated 6 times using 2 petri dishes as a replication for each treatment, with 5 seeds per petri dish. Prior to stratification or GA<sub>3</sub> treatments, buffaloberry seeds were scarified using sulfuric acid (SO<sub>4</sub>) for 20 minutes and rinsed with tap water.

All seeds were divided into 2 stratification treatments, air-dried for 3 days, and stored in sealed plastic containers. The stratification treatment started in May, with seeds received cool, moist stratification at 5 °C (41 °F) for 90 days. Stratification was accomplished by placing 60

seeds per pouch (fabric bag) in 1 polyethylene bag containing 454 g (1 lb) of moist germination media (peat moss). The remaining 240 seeds were immediately treated with GA<sub>3</sub> (Research Organics, Cleveland, OH) at 0, 250, 500, 1000 ppm. For each GA<sub>3</sub> treatment, sixty seeds were placed in beakers containing 120 ml (4 oz) of GA<sub>3</sub> solution and placed on a shaker at 175 revolutions per minute for 24 hours. Seeds were then placed on moist filter paper inside 47 mm (1.9 in) diameter petri dishes (Fisher Scientific, USA) using 2 ml (0.07 oz) of distilled water to maintain humidity. Petri dishes were placed on a lab bench at room temperature 18°C (65 °F) until seed radicle emergence. Stratified seeds were handled identically upon removal from the germination media after 90 days.

Germination was monitored every 3 days for all the seeds and recorded when emerged radicles reached a length of 3 mm (0.1 in). Data was collected over a period of at least 2 weeks, after germination began, and ended when no additional seeds germinated for 6 days. Data was subjected to ANOVA (Statistical Analysis System, SAS Institute Inc., Cary, NC) and the means separated by LSD test (p<0.05).

## Results and Discussion

### Red elm

Both Douglas and Butler County red elm seedlots exhibited similar trends in germination across the various treatments (Table 1); however, statistical analysis revealed a strong interaction between the stratification and GA<sub>3</sub> treatments. In general, non-stratified seeds showed a positive relationship between GA<sub>3</sub> concentration and germination; for example, as concentrations of GA<sub>3</sub> increased, so did germination percentage. Conversely, stratified seeds exhibited a negative relationship between GA<sub>3</sub> concentration and germination; stratified seeds that received increasing concentrations of GA<sub>3</sub> decreased in germination percentage.

For Douglas County red elm seeds, the highest germination occurred in the non-stratified, 1000 ppm GA<sub>3</sub> treatment. The stratified, 1000 ppm GA<sub>3</sub> treatment resulted in the lowest germination percentage (Table 1). For the Butler County seedlot, both the 500 and 1000 ppm GA<sub>3</sub>, non-stratified seeds performed similarly (Table 1); this treatment combination also yielded the highest germination percentages. Similar to the Douglas County seedlot, stratified seed exposed to 1000 ppm GA<sub>3</sub> had the poorest germination.

Germination of non-stratified red elm seeds was maximized with GA<sub>3</sub> at 1000 ppm. Previous work has indicated that stratification should increase seed germination (Dirr and Heuser, 2006). While this was true for the control treatment not exposed to GA<sub>3</sub>, 90-day stratified seeds that received GA<sub>3</sub> resulted in significantly less germination than non-stratified seeds. Thus, the GA<sub>3</sub> treatment exhibited a negative effect on germination of stratified seeds. This was shown by the strong interaction between the stratification and GA<sub>3</sub> treatments.

**Table 1.** Germination percentage of red elm (*Ulmus rubra*), gray alder (*Alnus incana*), and buffaloberry (*Shepherdia canadensis*) after gibberellic acid (GA<sub>3</sub>) and stratification treatments.

GA <sub>3</sub> concentration (ppm)	<i>Ulmus rubra</i> , Douglas County†		<i>Ulmus rubra</i> , Butler County†		<i>Alnus incana</i> ‡		<i>Shepherdia canadensis</i> ‡	
	Non-stratified	Stratified	Non-stratified	Stratified	Non-stratified	Stratified	Non-stratified	Stratified
0	13.3 c B	30.8 a A	30.0 b B	47.3 a A	3.3	8.3	5.0	6.6
250	28.3 bc A	22.3 ab A	50.0 b A	30.5 b B	8.3	5.0	5.0	0
500	45.0 b A	14.1 b B	73.3 a A	19.5 bc B	3.3	1.6	1.6	3.3
1000	78.3 a A	5.6 c B	86.6 a A	2.8 c B	10.0	3.3	1.6	0

† Within a county, means within a column (lower case) or row (uppercase) followed by the same letter were not significantly different (LSD p < 0.05; n = 6).

‡ No significant difference (LSD p < 0.05; n = 6).

One explanation for this may be a supraoptimal response of stratified red elm seeds to treatment with GA<sub>3</sub>. Non-stratified seeds benefited from exposure to exogenous GA<sub>3</sub>, while stratified seeds (which naturally produce endogenous GA<sub>3</sub>) experienced an apparently toxic or inhibitory response when exposed to additional GA<sub>3</sub>. This relationship will be an important one to investigate in the future.

## Gray alder

It has been suggested that gray alder seeds can benefit from 60 to 90 day stratification (Schalin 1967; USDA 2011a), but this study found no significant differences among either stratification or GA<sub>3</sub> treatments. Unlike red elm, gray alder experienced overall poor germination with both stratification and GA<sub>3</sub> treatments (Table 1). Results suggest that further work is needed to improve seed propagation of gray alder; under these treatment conditions, seed propagation may not be a viable option for mass production of this species.

## Buffaloberry

Similar to gray alder, no significant differences were detected between stratification and GA<sub>3</sub> treatments. Overall, germination was very low among all treatment combinations < 7% (Table 1). A previous study (Dirr and Heuser, 1987) recommends scarification for 20 to 30 minutes followed by a period of 2 to 3 months stratification. Other authors (Krishnan et al. 1991) recommend that buffaloberry be rooted by cuttings due to the low viability of the seeds.

## Summary

Based on this study, we recommend non-stratified red elm seeds to be soaked in 1000 ppm GA<sub>3</sub> for 24 hours before sowing. Seeds typically took 10-15 days to germinate. Future studies should evaluate higher levels of GA<sub>3</sub> and shorter stratification periods to

determine optimum rates for maximum germination. A study using higher concentration of GA<sub>3</sub> (500, 1000, 2000, 4000 ppm) is currently being conducted to determine the upper limit to improve germination. We do not have seed treatment recommendations for gray alder and buffaloberry due to the poor germination displayed in this study. Additional studies will examine rooting capacity with dormant and greenwood cuttings of the 3 species.

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# Perry Pinyon Pines Protection Project

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McCarthy D. 2012. Perry pinyon pines protection project. In: Haase DL, Pinto JR, Riley LE, technical coordinators. National Proceedings: Forest and Conservation Nursery Associations—2011. Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. Proceedings RMRS-P-68. 96-101. Available at: [http://www.fs.fed.us/rm/pubs/rmrs\\_p068.html](http://www.fs.fed.us/rm/pubs/rmrs_p068.html)

**Abstract:** Fuel reduction treatments around pinyon pine trees began as a simple project but ended in something more complex, enjoyable, and rewarding. The project eventually led to pinyon species (*Pinus monophylla* and *P. quadrifolia*) reforestation efforts, something that has been tried in the past with disappointing results. The Perry Pinyon Pines Protection Project and current efforts at propagation are described for areas on the San Jacinto Ranger District, San Bernardino National Forest, and on the Ramona and Santa Rosa Indian reservations. A greater measure of success in propagation of these pinyon species has been obtained through a better understanding of their environmental needs.

**Keywords:** Fuels reduction, *Pinus monophylla*, *Pinus quadrifolia*, propagation

## Introduction and Background

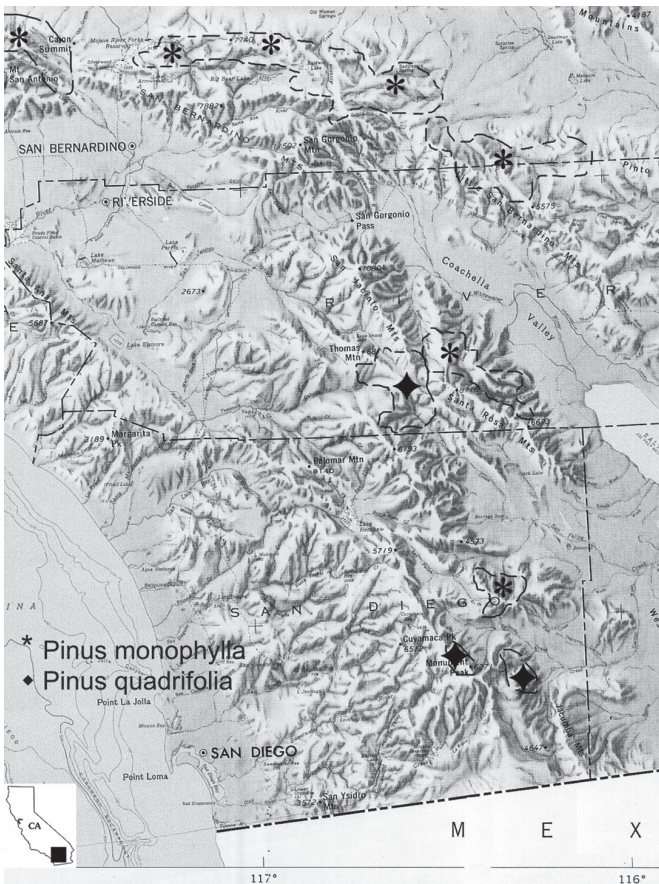
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The San Bernardino National Forest (SBNF) is host to 2 species of pinyon pine, *Pinus monophylla* (singleleaf pinyon) and *P. quadrifolia* (Parry pinyon). Singleleaf pinyon generally grows on the north slopes of the Transverse Mountain ranges, including the San Bernardino Mountains and on the southeast portion of the San Jacinto Ranger District (SJR) in the Santa Rosa Mountains (Figure 1). In the San Bernardino Mountains, singleleaf pinyon is represented by extensive forests covering hundreds of thousands of acres. Singleleaf pinyon is represented in the Santa Rosa Mountains by moderate-sized forests to small groups of trees across portions of Pinyon Flat, Little Pinyon Flat, Pinyon Alta Flat, and areas in between.

In recent years, wildland fires have destroyed tens of thousands of acres of this habitat. In the northern Peninsular Range, within the Santa Rosa Mountains, singleleaf pinyon (also described as *P. californicum* after Bailey 1987) is found on the desert side (rain shadow effect) usually between 3800 and 6000 feet in elevation. The drought has affected this species drastically with thousands of trees dying between the years 2001 and 2008. In 2010 and 2011, singleleaf pinyon mortality seems to have been significantly reduced.

Parry pinyon grows on the southwest side of the SJRD, generally in the southern end of Garner Valley; also on Vandeverter Flat on the Santa Rosa Indian Reservation and western end of the Santa Rosa Mountains; on the southern end of Thomas Mountain; and on the north end of Anza Valley including the Ramona Indian Reservation (Figure 2). These populations are the northern extent of the range of the species which continues sporadically southward into San Diego County and northern Baja California where isolated, dense stands may occur. In Riverside County, the species grows from 4200 to 5700 feet in elevation. Today, with nearly 100 years of fire suppression activity and the suspension of native burning and traditional gathering practices, chaparral vegetation is very dense where this species grows. Forest populations are sporadic across the landscape, represented by single trees, several trees, to under several hundred trees in relatively small areas of 2-20 acres. Presently, surviving trees favor north facing and steep slopes of side drainages. They are found infrequently in the south half of the valley floor in Garner Valley today, but this may reflect recent historical land uses of clearing, firewood collection, and past fire history. For the past 100 years, this species has been much affected by wildfires thereby reducing their numbers and likely their distribution within this range. This species does seem to be much less affected by the drought, and mortality is noticeably less in recent years when compared to singleleaf pinyon in this area.





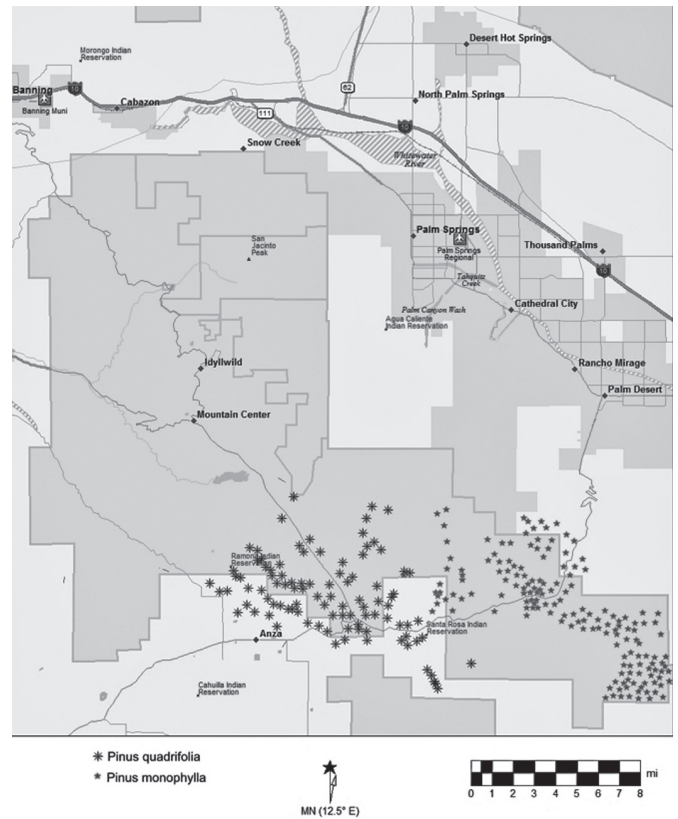
**Figure 1.** Singleleaf (*Pinus monophylla*) and Parry pinyon pine (*Pinus quadrifolia*) species distribution in southern California.

Both pinyon species are culturally important to the Cahuilla Indians and other southern California Tribes (Lanner 1981). *Tevat* is the Cahuilla Indian word for pine nut, and *Tevatwic* is the name for Parry pinyon. The suffix indicates “fat pinyon” and was held in high regard for its flavor and nutritional value (Bean and Saubel 1972).

## Parry Pinyon Pine Protection Project

In 2005, at the request of the Ramona Band of Cahuilla Indians, a collaborative effort was explored with the SBNF initiating the Parry Pinyon Pines Protection Project (P4 Project). The Tribe, requesting under the authorities of the Tribal Forest Protect Act (2004), sought assistance in protecting Parry pinyon from catastrophic fires. The project was designed to partner with the Ramona Band and later the Santa Rosa Band of Cahuilla Indians. Parry pinyon occurs on both reservations which are within or adjacent to National Forest Lands.

Between 2004 and 2010, the SBNF fuel reduction program continued across the forest to remove dead trees and thin vegetation after the devastating last few years of drought and insect infestation. The P4 Project’s effort has focused on removing the brush around the individual Parry pinyon pine trees. The concern is over the amount of vegetation build-up (undergrowth) near these trees. If a wildfire breaks out, these trees would not survive. By clearing away the vegetation and limbing lower branches, a wildfire could potentially burn around or under the trees and not cause lethal harm. This, in conjunction with the larger effort of fuels thinning and defensible space, will provide for better protection of the species from catastrophic fires. It will be much easier to defend existing trees than attempt reestablishment via seedling planting after a deadly wildfire.



**Figure 2.** Singleleaf (*Pinus monophylla*) and Parry pinyon pine (*Pinus quadrifolia*) species distribution in the San Jacinto and Santa Rosa mountains.

This project consisted of removing vegetation around the base of individual trees to create a ‘safe’ or buffered zone against future wildfire. By creating the appropriate-sized buffer zone, severe and fatal fire effects can be reduced around the tree while at the same time preparing for prescribed burning or other fuels reduction treatments. It will also make the trees accessible for cultural gathering when there are cone crops. The P4 Project has had many benefits, including: satisfaction of management direction from Congress (e.g. earmarks), the Washington Office, or the Regional Office; contributing to meeting a target (fuels treated); protecting resource integrity to preserve and enhance future options and ensure there is no irrevocable loss of the resource base; enhancing the health and vigor of our resources and infrastructure; providing an opportunity for public involvement and education; having significant public benefit, such as affecting the local economy or numerous people; getting kids into the woods; and adhering to or implementing Forest strategic and tactical plans.

In 2005, both the SBNF and Santa Rosa Indian Reservation conducted independent efforts to gather pinyon cones with the intention of propagating the seeds for planting. The SBNF sent their collected seeds (both singleleaf and Parry pinyon) to a nursery in Placerville, California. The seeds had a very high germination success rate and over 4500 seedlings were propagated. In April 2007, the seedlings were transferred to the SBNF. Because winter precipitation during 2007 was unusually low, and contributed to dry soil conditions into the spring, most of the seedlings were placed in pots or heeled-in for fall planting. It was hoped that after summer and fall rains resumed, that conditions would be improved for planting. However, many of the seedlings remained heeled-in due to continued drought conditions

and reduced workforce. Batches of trees were planted as time and windows of opportunity became available.

In April 2007, approximately 40 Parry pinyon seedlings, from the seed collected by the Santa Rosa Tribe, were planted on the reservation, where they continue to be monitored by tribal members. Other plantings have been undertaken in subsequent years, but the project emphasis has been primarily on fuel reduction surrounding pinyon trees.

The P4 Project was seen as on-going, similar to the way fuels reduction and healthy forest activities are. Over the last 6 years, efforts to protect specific trees were conducted at several locations on National Forest Lands and on Santa Rosa and Ramona Indian Reservations. Hundreds of trees have been treated within several hundred acres (Table 1). Over 1200 hours were volunteered in support of the project over the 6 years. Several volunteers returned each year and interest steadily increased; unfortunately, the lack of funding has curtailed the project.

### Pinyon Pine Characteristics

Parry pinyon populations are small and widely scattered. We know it is possible for a single fire to eliminate 90 percent of the population. Thus, it is necessary to increase the number of stands within its range. If (or when) a large, catastrophic wildfire occurs, the Parry pinyon will be lost with no surrounding populations to support regeneration. Unlike many other species, seeds do not lie dormant in the soil creating a seed bank. Consequently, there are no pinyon seeds to sprout and carry on the next generation after a fire. Seed dispersal is contingent on being spread by birds, particularly jays: Steller’s jay (*Cyanocitta stelleri*), western scrub-jay (*Aphelocoma californica*), and pinyon jay (*Gymnorhinus cyanocephalus*). Jays collect the seeds and fly about often dropping, planting, or losing them among the shrubs. If there are no shrubs in the burned area after a fire, jays are unlikely to fly into the area and spread pinyon seeds for future seedling establishment. Moreover, if maximum seed dispersal did occur in a burned area, without adequate ground cover (small shrubs) the pinyon seeds would not be successful in surviving because of the harsh conditions. When planting after a fire, it is necessary to wait until there is sufficient ground cover or provide shade of some sort to create adequate microsites for the establishing seedlings.

It is now recognized that seedlings need a proper environment to get established and survive. This includes having a ‘nurse’ plant to protect against harsh establishment conditions. Nurse plants are hypothesized to offer benefits to establishing seedlings by protecting them from direct sunlight, mitigating extreme soil temperatures, and

eliminating grass competition for surface water (Figure 3). Since the beginning of the project, it has been noted that all of the natural regeneration is occurring in dense vegetation (chaparral conditions; Figure 4); no seedlings have been observed growing alone or unprotected by some other shrub. This is further supported by observing that many of the young trees (less than 6 feet tall) are growing up inside or among other shrubs.

In a search for younger surviving singleleaf pinyon trees, it was concluded that many of the trees were growing in the northeast aspect of the vegetation cover. These younger trees are less than 5 feet in height. The chaparral community consists primarily of ribbonwood (*Adenostoma sparsifolium*), chamise (*Adenostoma fasciculatum*), scrub oak (*Quercus palmeri*, *Q. berberidifolia*), sagebrush (*Artemisia californica*) and manzanita (*Arctostaphylos* sp.). Some of the areas being treated for fuels have not burned in many decades and vegetation cover is often very dense and over 3 meters in height. Yet natural pinyon seedlings are doing very well. Eventually they grow tall enough to reach sunlight, and as time goes on, they become the dominant cover crowding out the less shade tolerant plant species. It appears that it may take up to 10 years before the needles harden and become acclimatized. After this period, the young trees can survive full exposure to the sun and other environmental conditions.



Figure 3. Pinyon seedlings emerging at the base a ribbonwood shrub (*Adenostoma sparsifolium*).

Table 1. Parry pinyon pine protection project accomplishments by site.

Location	Fuels Treatment (acres*)	# of Seedlings Planted
San Bernardino National Forest		
Thomas Mountain	75	-
Garner Valley 1	-	125
Garner Valley 2	-	10
Garner Valley 3	-	15
Garner Valley 4	2	-
Garner Valley 5	10	80
Ramona Indian Reservation	75	55
Santa Rosa Indian Reservation	80	85

\*1 acre = 0.4 hectares



Figure 4. Pinyon pine habitat in southern California. The tops of Perry pinyon (*Pinus quadrifolia*) can be seen above the dense chaparral at the south end of Thomas Mountain Ridge.

## Mapping the Distribution of Singleleaf and Parry Pinyon Pine

Little data is available about the distribution of singleleaf and Parry pinyon pines on a macro scale, let alone a micro scale. Early mapping and distribution efforts were satisfied with plant community mapping not specific to species. As a result, mapping became a priority for the P4 Project. It was deemed important because: 1) knowing where they grow today can provide protection from fuels projects or other management decisions in the future; 2) understanding their current range can give insight to their historic range; and 3) knowing their current distribution would prioritize outplanting efforts to increase populations and prevent habitat loss by catastrophic wildfire.

As a result of the P4 Project efforts, mapping of the species in Riverside County is complete. Stands of pinyons and individual trees are mapped at the 7.5' scale. These maps (covering U.S.G.S. 7.5' quads: Anza, Idyllwild, Palm View Peak, and Butterfly Peak for Parry pinyon; and Butterfly Peak, Rancho Mirage, Toro Peak, and Martinez Mountain for singleleaf pinyon) are now digitized and part of the SBNF corporate database. The presence or absence of pinyon trees is indicated. Figure 2 provides a general view of tree distribution for the 2 species.

## Thinning, Restoration, Site Selection, and Regeneration Efforts

Subtle differences may exist between the successful propagation of singleleaf and Parry pinyon pine seedlings, but the differences have not yet been recognized. The treatments described here refer to both species. Natural habitat is similar for both species. While the surrounding vegetation around Parry pinyon is dense, vegetation around singleleaf pinyon is more open and contains a wider variety of shrubs. Because of this openness, no thinning treatments were conducted for singleleaf pinyon; all efforts focused on Parry pinyon.

The P4 Project was designed to have public volunteer participation. Volunteers were needed to help cut, clear away, and pile the treated vegetation. Only hand tools were used. Weekend activities were advertised in advance to attract interested parties. These advertisements explained the nature of the project and its importance. Native Americans participated in the project and shared their views on traditional gathering and uses of not just pinyon but other plants important to the local tribes. During the last 3 years, the first weekend (of 3 consecutive weekends) of the project was scheduled to begin on National Public Lands Day. Free camping was arranged at a SBNF campground for those who wanted to stay overnight during each weekend of the project.

When the project dates overlapped with a pinyon cone production year, pine nuts were gathered with the intent of seed propagation and outplanting. One of the communities was encouraged to collect seed from around their property. To facilitate this effort, a presentation was given outlining collection and storage techniques; the presentation also outlined how the seedlings would eventually be propagated. Many misunderstandings exist about pinyon pines. For example, it is common to think pine nuts need to be roasted before they are consumed, when in fact, they can be eaten raw. Some argue that roasting improves the flavor, but this process kills the embryo and allows for long-term storage and later consumption. Another misconception is the collection of green cones. While some thought it was not good to do this, it was explained that fire or kiln drying can be used to help open the scales for extracting the nuts. Some confusion also exists around the maturation of cones and cone bearing years. While it is true that it takes 2 years for a pine to produce a cone (once it is pollinated), good cone bearing years only occur once every 5 to 7 years depending on precipitation (Krugman and Jenkinson 1974).

The focus of the P4 Project was to thin vegetation specifically around pinyon trees (Figure 5 A&B). Areas were selected mostly because they were accessible by vehicle and there was a great need. Some areas were chosen because they had good defendable space; that is, they were associated with other fuel breaks, roads, or treatment areas that had a head start in fuels reduction. Volunteers were used over several weekends in late September and early October each year to coincide with a possible harvest of pine nuts. As the project grew, so did the accomplishments and outputs. In the fall of 2010, after a very good crop year, volunteers gathered hundreds of seeds. Over the winter, experiments investigated the best ways to germinate them. From these trials, many seeds did sprout and some have already been planted. Others were delegated to reforestation efforts where many trees have been lost to wildfires.

Documented restoration planting of pinyon pine species has not been successful following fires (Gifford 1987, 1994). This failure may be the result of planting in the open, without any vegetation cover to shade/shelter the seedlings (i.e., to act as a nurse plant).

Since Parry pinyon needs a nurse plant for protection from intense sunlight for the first 10 years or so (based on current observations), vegetation is thinned, but not eradicated, in the area surrounding young seedlings to prevent spread of wildfires. As the seedlings grow into mature trees, they will eventually dominate and become the overstory. Vegetation cover is critical in selecting areas to plant seedlings.

## Project locations

The projects were implemented on National Forest System Lands and on the Ramona and Santa Rosa Indian Reservations. Figure 6 shows the general areas of where planting and fuels treatments took place.

As seedlings became available for planting, suitable areas were selected. Several areas in Garner Valley were selected because they were: deemed suitable habitat; near existing Parry pinyon populations; or determined to have been within its historic range. These areas are designated as Garner Valley #1, #, #3, #4 and #5 (Table 1).

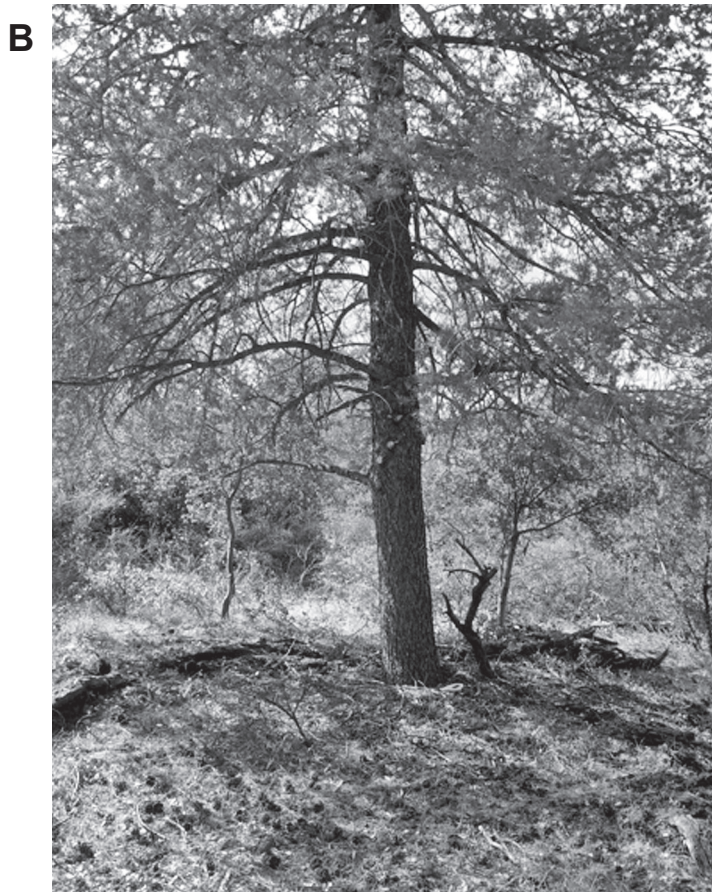
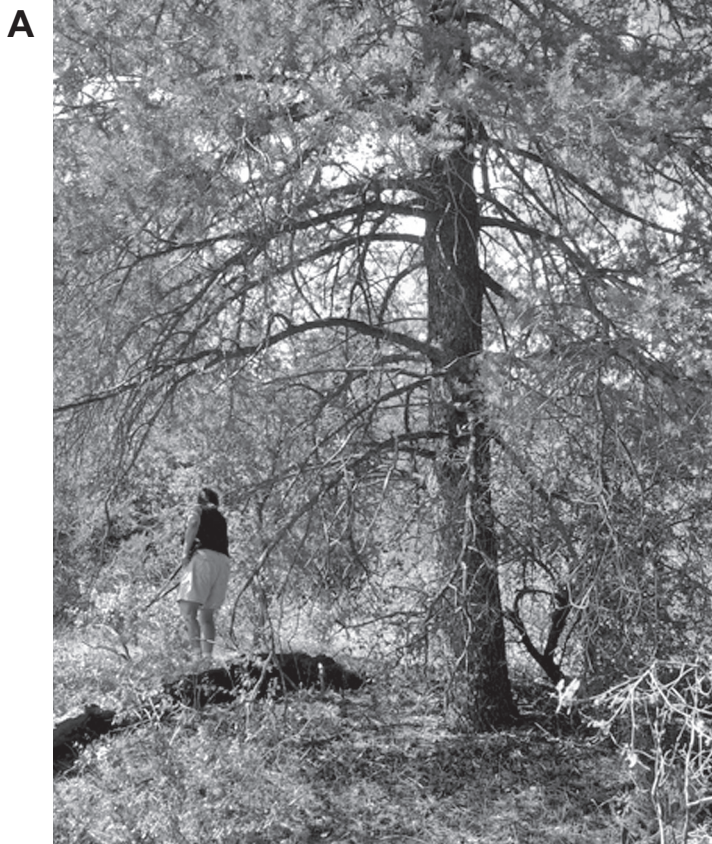
During the time period when Parry pinyon could not be treated, the P4 Project continued working on the Ramona and Santa Rosa Indian Reservations. No new trees were planted on the Ramona Reservation. Previously planted trees were monitored and mortality was less than 40 percent during the first year.

## Thomas Mountain

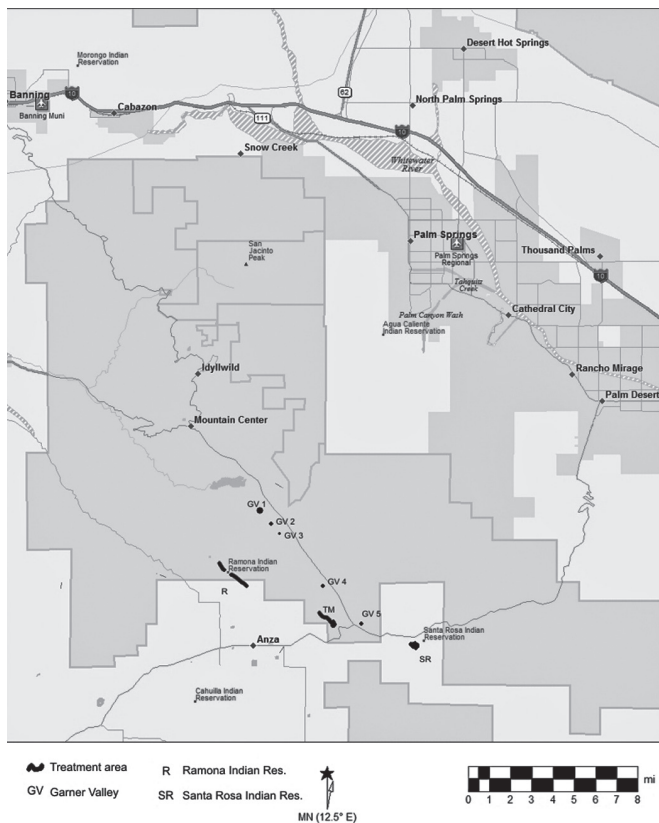
This was the area first selected to begin the project on SBNF lands. Many existing pinyon trees were adjacent to the road and an old fuel break. Other general fuels treatments were proposed that would enhance the efforts of the P4 Project. Environmental issues rose when the Quino Checkerspot Butterfly (*Euphydryas editha quino*) was observed. This species is listed on the Endangered Species List. Due to sensitive habitat issues, our project work in this area was suspended in 2009 and 2010 until consultation with Fish and Wildlife Service (FWS) could be completed. After the consultation, the FWS agreed that the P4 Project did not threaten the species but may enhance the habitat for the butterfly. See Table 1 for accomplishments.

## Garner Valley #1

In March 2009, approximately 100 Parry pinyon seedlings were planted in a 10 acre area west of the CALTRANS Maintenance Station in the central part of Garner Valley. Three young, immature trees were identified during the mapping of the distribution of the species. These trees are located about 500 meters southeast of the planting area. These trees are less than 15 feet in height and may not be of cone-bearing age yet. The seedlings were monitored, and tree



**Figure 5.** Thinning vegetation around the base of trees and limbing branches when necessary: before treatment (A) and after treatment (B).



**Figure 6.** Seedling planting and fuel reduction locations of the Parry pinyon pine protection project.

mortality totaled about 40 percent after the first year. Rodent activity (gophers) seemed to be the primary reason for mortality but range cattle also may have contributed. An additional 60 seedlings were planted in 2011. Precipitation has been adequate and frequent enough to provide sufficient moisture for survival.

**Garner Valley #2**

Also in March 2009, a dozen seedlings were planted under the canopy of a live oak stand. All seedlings have done well.

**Garner Valley #3**

This unit is in a short, narrow draw that leads west from a power line road. Vegetation provides good cover and water was noted in the drainage over the 2009 and 2010 winters. Seedlings were planted where scrub oak, manzanita, and ribbonwood vegetation provided the most shade.

**Garner Valley #4**

This unit is located on the east facing side of the foothills within a steep drainage overlooking Garner Valley. The area contained dozens of pinyon trees of various ages amongst the dense vegetation. These trees are likely providing the seed stock for other younger trees growing nearby. In 2009, thinning was the focus of the project; however, much more work needs to be accomplished here in order for the efforts to be effective.

**Garner Valley #5**

The unit is located adjacent to private property along a fuel break to protect the community. This unit was planted with seedlings in June

and again in October 2011. For both plantings, the planting window was optimized so that natural precipitation provided adequate moisture and no supplemental watering was necessary. At last look these seedlings were doing fine. Local community residents have taken an interest in this project and have volunteered to monitor the seedlings, planting more when necessary.

## Ramona Band of Cahuilla Indians Reservation

The Tribe originally requested assistance in 2005, resulting in the P4 Project beginning the following year. Fuel reduction and planting efforts has been very successful (Figure 7).

## Santa Rosa Band of Cahuilla Indians Reservation

Tree planting and fuel reduction began in 2007. Volunteers including students from Sherman Indian School in Riverside have participated.

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## Facts about Pinyon Pine trees

1. Four species of pinyon pine can be found throughout the southwest (and many more worldwide), all producing an edible nut that has been sought after by native people for thousands of years.
2. Pinyon seeds do not remain viable for very long (less than a year), so there is no seed bank in the soil after a burn.
3. Young pinyon seedlings can grow 1 to 3 inches in height each year during the first 6 years.
4. Pinyon trees can be slow growing. Parry pinyon may be 15 to 25 feet tall before it reaches maturity and more than 25 years old before it produces cones. Singleleaf pinyon are 20 to 50 feet tall before they reach maturity and must be 20 to 25 years old before they produce cones.
5. Both Parry and Singleleaf pinyon trees can reach ages well over 350 years.
6. Like most other pine trees, pinyons take 2 years to produce a cone and seeds. Good pinyon crops are produced every 3 to 5 years depending on climatic conditions.
7. The largest known Parry pinyon is located north of Anza, California. It has been submitted as a Champion Tree in the American Forests: National Register of Big Trees.
8. Native American gathering and burning practices likely helped to protect the trees.
9. The needles of all pines can be boiled to make a tea that is high in vitamin C.
10. Pine needle baskets were made from pine trees that have longer needles (5-7 inches), not the pinyon.
11. Pine nuts can be eaten right from the cone; they do not have to be cooked or prepared.
12. Roasting pine nuts improves flavor and allows longer storage time for later consumption.
13. Pine pitch can: seal baskets to make them water tight; be a sun screen when applied to the face; and repair broken objects when used as a glue.



**Figure 7.** Two examples of tribal members clearing vegetation from trees on the Ramona Band of Cahuilla Indian Reservation

The content of this paper reflects the views of the authors, who are responsible for the facts and accuracy of the information presented within.



# Participants:

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

**Western Forest and Conservation  
Nursery Association Meeting**

**Intertribal Nursery Council Meeting**







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

Huntington, West Virginia (July 25 to 28, 2011)

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# Western Forest and Conservation Nursery Association Meeting

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