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Planting Guide for Hybrid Poplar (Populus simonii) in Kulun Qi, Inner Mongolia

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Abstract

The Shanghai Roots & Shoots office of the Jane Goodall Institute is undertaking to plant 1 million seedlings near the city of Kulun in Inner Mongolia. A primary need of this effort is a planting guide specifically aimed at the harsh conditions faced by local farmers in trying to afforest large portions of the local desert. This paper outlines the key practices to be followed to attain successful afforestation in the area.

内蒙古库伦旗杂交杨树种植指导手册

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摘要

作为中国唯一一家获准注册的涉外环保公益机构，上海根与芽青少年活动中心在内蒙古库伦旗地区开展了大规模的植树造林活动以改善当地的生态环境。上海根与芽的目标是在该地区种植一百万棵树！由于库伦旗沙化地区的地理气候条件特殊，确保树苗栽种的成活率是整个项目成功的关键。本手册的目的即帮助库伦当地的农民更好地了解如何采用正确的方法植树造林，从而达到最好的生态效果。

Introduction

Populus simonii is the species of choice for planting the sandy lands in the Kulun Qi area of Inner Mongolia (Lu 2001). Much has been published on the agricultural development problems and successes in the County of Kulun, or Kulun Qi, which is part of the Tongliao Prefecture (Brogaard and Li 2005) (figure 1). There is no doubt whatsoever that the planting of *Populus simonii* in the broad expanse of desert (figure 2) will benefit the local farmers with land stabilization. Many other species can be planted in the area, as well (Forest Society of Tongliao City 2003).

The necessity for planting in Inner Mongolia is well understood (Katoh and others 1998; FAO 2000; Zhao and others 2006). Historically, the area was mostly grass, forbs, shrubs, and trees, but decades of overgrazing have reduced the vegetation to xeric plants that dot the landscape. The spread of agriculture led to the destruction of the fragile soil, which in turn led to wind erosion. Unable to keep up with the shifting sand, the owners abandoned much of the land.

The environment in the area of Kulun Qi is marked by very cold, harsh winters in which the temperatures dip below 0 °C (32 °F). The winds create an even more negative wind chill factor. The snows are heavy. The soils are primarily sand, especially in those abandoned areas where tree planting is most needed.

The challenges faced in afforesting such an area are many (Carle and Ma 2005). As harsh as winter is, spring comes

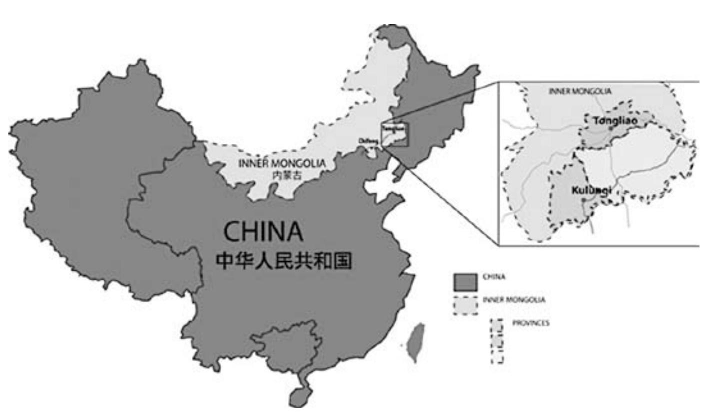

Figure 1. Map showing the general location of Kulun Qi or Kulun County in Inner Mongolia.

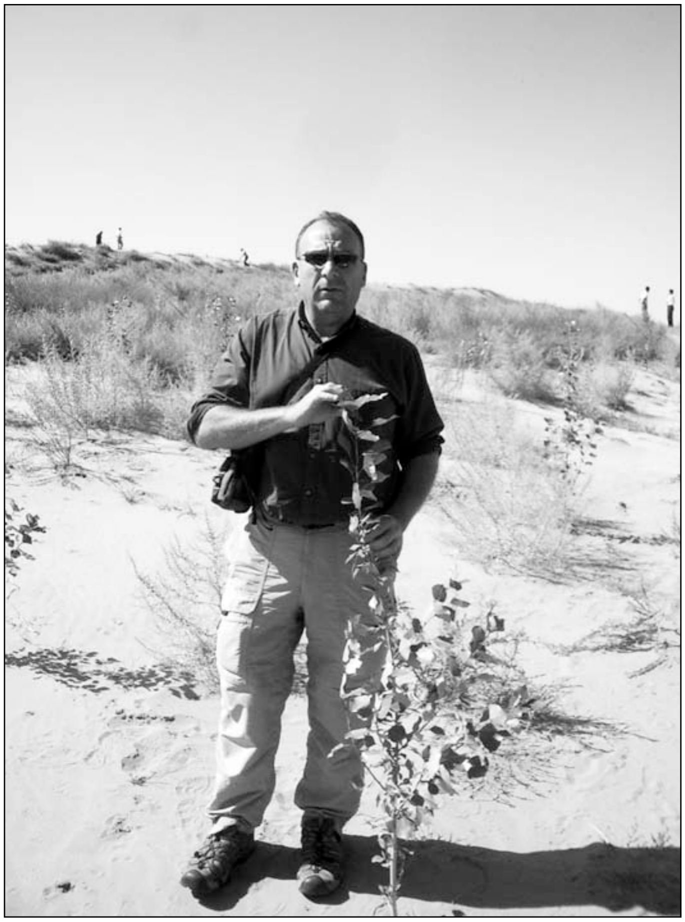


Figure 2. Joe Tatelbaum (left) and Tori Zwisler, volunteers of the Jane Goodall Institute–Shanghai, Roots & Shoots Program, with successful plantings of cottonwood in Kulun Qi in April 2007.

quickly. The snow melts rapidly and for a time replenishes some of the subsurface ground water. This is the water that the cottonwood plantings can make the most use of in order to establish good root-soil contact. As the summer progresses, evaporation increases and root access to soil water moves deeper. The prime reason for the very deep planting of cottonwood cuttings [up to 1 m (3.3 ft) deep] is because of the need to access moist soil as the summer temperatures rise into the 42 °C (107 °F) range and higher.

The purpose of this paper is to specify recommendations and procedures for the successful planting of cottonwood (*Populus* spp.) in the Kulun Qi area of Inner Mongolia. The Shanghai Roots & Shoots Office of the Jane Goodall Institute has undertaken to plant 1 million trees near the City of Kulun to support local agroforestry operations, as well as to fix carbon to combat global climate change. Cottonwood is often planted in riparian areas in more temperate climates, but this area is extraordinarily harsh in both winter and summer. Site-appropriate procedures, from the timing of lifting in the nursery all the way through to handling at planting, are key to attaining successful afforestation, which could be defined as greater than 90 percent survival at the end of the first growing season.

Methods for Successful Afforestation

Production and assessment of planting material. Cottonwood seedlings are grown from cuttings. These are derived from stool beds: sections of stem material, cut into lengths of 30–40 cm (12–16 in), are planted into bareroot beds and grown for 1 yr, usually to a height of 1.5 m (4.9 ft) or more. In order to obtain 1-yr cuttings for field planting, these seedlings are cut at ground line in spring, bundled, stored moist, and shipped to the field for planting as “whips” or long stems without roots. The rootstock left in the nursery bed is then allowed to produce a new shoot and grow another year, yielding 2-yr-old seedlings. The whole plant (root and stem) then is dug up in spring, bundled, kept moist, and shipped to the field.

There are permutations of this process, such as lifting cuttings in the fall of the first year and either storing the cuttings in a refrigerated cooler or storing the cuttings horizontally under several feet of soil in the ground. If stored in the ground, the cuttings are dug up in the spring, kept moist, and then shipped to the field. The same can be done for 2-yr-old seedlings.

The type of seedling used in planting operations is not critical. Cuttings without roots can do just as well as those with roots. Keeping the seedling tissues hydrated (moist) all the way to the planting hole will give the highest incidence of root development and planting success, as measured by high survival and growth.

At the time of planting in the field, the minimum morphological dimensions should be ≥1 m (3.3 ft) in height and ≥5 mm (0.2 in) in diameter at the base of the cutting. The diameter of a cutting with roots is measured at ground line. The seedlings should be devoid of defects, such as cambium scars; the buds should be large; and no part of the plant should show cold damage.

Seedlings with roots should be checked for stripped roots, in which the outer sheath over the xylem has been stripped away. Stripped roots look white or may appear rotted, depending on how the seedlings were handled. Some stripping is to be expected, but some care should be taken during lifting to minimize this problem.

Also make sure that the seedlings have healthy axillary buds at lifting and planting (Radwan and others 1987). It is wise to take a razor blade or sharp knife and cut some buds vertically to see if the buds have suffered cold damage, which will appear black or brown. A cold-damaged bud will not grow. The same thing can be done to check for browning in the cambium. Brown cambial tissue is dead. Such physiological damage will greatly retard active growth after planting and may even mean rapid mortality. In some severe cases, the seedlings are not worth planting because they are already dead. Green cambial tissue is live tissue and a key target characteristic (Rose and others 1990).

Planning and preparation. Success in afforestation depends a great deal on good planning, good organization, and availability of the proper equipment. It is important to preassign the lands to be planted, make arrangements for local planters to be available, and determine how many seedlings (cuttings) will be needed to plant the area.

Great consideration needs to be given to how long it will take to get the seedlings to the site from the nursery, how the seedlings will be cared for before and during planting, and whether water will be available. Given that the Kulun Qi area is desert with deep sands, it is especially critical that the seedlings be kept moist at all times up to being placed in a moist planting trench or hole and that the seedlings be planted within no more than an hour of trench or planting hole preparation. The sandy soils dry out so quickly that moisture will be lost to the newly planted seedlings if the seedlings are not planted and trenches or holes filled in quickly. It is not good practice to get all of the seedlings into position for planting and then realize that the bulldozer-trencher or planting crew will not be available for another 5 d.

Even daily local weather conditions must be taken into account. One long-standing rule of thumb is that weather conditions that the planters find ideal likely are not very good for the seedlings. Arrangements need to be made in advance should seedlings need to be stored locally for planting, even for several days, until weather conditions improve.

Site selection and planting layout. Where seedlings are planted on the landscape has a lot to do with planting success. In the Kulun area, the land appears flat for hundreds of kilometers, yet, in terms of microtopography, the ground is highly variable. To attempt to plant every square meter is very unwise.

In terms of strategies for planting dunes, much depends on preplanning and understanding the variable shapes of dunes and their accessibility to heavy equipment. Careful consideration must be given to planting between dunes, where the ground is flatter and it is easier to get the trenching equipment deep enough to reach moist soil. It is necessary to get the cuttings down to a 1-m depth, and it can be very difficult for a trencher pulled behind a bulldozer to get down deep enough along the slope or top of a dune. Dunes may also require cover species other than cottonwood in order to be stabilized, due to the exposure to winds, shifting sand, and greater depth to moist soil.

All sites chosen for planting should be carefully laid out before beginning operations. It is important to know the size of the area to be planted, the number of seedlings (plus 5 percent) that will be required to cover the entire area, and the spacing and layout to be used. Consideration needs to be given as to how many seedlings will be planted in a row, how many rows will be planted, and how far apart the rows will be.

The layout should take into account the changing sand depth across the site and the presence of dunes. The sand is likely to be deeper on the rising shoulders of a dune, which can lead to planting failure if the planting holes are not deep enough to get the roots into moist soil. The idea is to get the flatter areas and lower spots between dunes successfully growing trees and come back later to plant the dunes with more drought-hardy species.

For a plantation planting, the seedlings are commonly planted 1.5–3 m (1.6–3.3 yd) apart in the row and the rows are placed 2–3 m (2.2–3.3 yd) apart. Usually dense spacings are used if the local people intend to harvest some of the saplings for stakes in the next couple of years, taking every other sapling in a row. In agroforestry plantings, it is common to plant the seedlings 1.5 m (1.6 yd) apart in the rows and space the rows 4 m (4.4 yd) apart. The area between the rows is used for crops such as beans and corn.

Site preparation. The common way to plant cottonwood in dune areas is to use a bulldozer with an attached trencher. The trencher plow digs a trench that is 30–40 cm (11.8–15.7 in) wide and around 50 cm (19.7 in) deep. It serves no purpose to dig the trenches the day before planting, because the sandy soil will dry out. Depending on the distance between trenches (furrows), this depth usually moves enough sand from the surface to reach moist soil. At 50 cm (19.7 in), the planters can dig another 50 cm (19.7 in) deeper, if necessary, to get the seedlings into moist soil and fill in the hole with moist soil.

Moving the seedlings from nursery to field site. One of the most critical aspects of any planting operation is transporting the seedlings to the site. This is so critical because the best success in desert regions such as Kulun is usually obtained through a technique called “hot planting.” This technique requires that the seedlings be lifted in the nursery within 24–36 h of field planting. The seedlings are often lifted the day before planting, stored at the nursery or carried to the site for storage, and planted the next day. The purpose is to sustain physiological quality by reducing any stresses on the seedling between the nursery and the field environment. Coordination between the nursery manager and the field-planting supervisor is necessary to ensure the timely delivery of seedlings in good physiological condition to the planting site.

Minimizing seedling stress during transport and planting. The seedlings are at the greatest risk of physiological and morphological damage once they leave the nursery because of several factors.

(1) Seedlings that are not kept moist will desiccate, which will lead to moisture stress after planting.

(2) Seedlings that are poorly bundled and roughly treated will end up with scraped cambiums, which creates wounds that can be vector points for disease, insects, and stem weakening.

(3) If the travel time to the field planting site is long and the seedlings are not properly protected, afforestation may be less successful because the seedlings have become physiologically ill equipped to survive.

(4) In too many planting operations worldwide, one of the greatest hazards to successful afforestation has been the mishandling of seedlings just before planting. Perfectly good seedlings are left out on the ground, only to dry out while awaiting the digging of a hole.

Soaking the seedlings is very important to rooting success (Randall and Krinard 1977; Krinard and Randall 1979; Derochers and Thomas 2003). It is good practice to soak the seedlings for 24 h in water before planting. This can be done in the nursery, either by keeping the seedlings in moist soil, out of the wind, before lifting or by wrapping the seedlings in moist burlap.

Seedlings should always be kept moist during transport from the nursery to the planting hole. Keep the seedlings covered in wet burlap or wet them before covering them with a tarp. They should never be left out on carts in the sun and wind. The planting supervisor should bring only the number of seedlings to the site that can be planted in one day or one morning. This is especially important for seedlings or cuttings with roots; root tissue is highly vulnerable to desiccation, much more so than stem (bark) tissue.

Planting. *Weather and planting conditions*. The planting season is important to cottonwood success in this desert region. Usually spring planting in April works best because the belowground soil has been charged by winter snow. It is important that the planting not take place when snow might get into the planting hole to create air pockets after melting. Although it is impossible to predict the optimal window of opportunity for planting, it is good to get started with planting as soon as the soil has warmed to above 10 °C (50 °F) and has moisture.

One factor that is so often overlooked in planting is the time of day and the weather conditions throughout the time of day. Early morning, just after sunup, commonly is the best time to plant. The best conditions are when it is cloudy and cool. Winds should be 0 to <10 km h^{-1} (6.2 mph) if possible. As the morning progresses and the sand warms up, the sand likely will get hotter and windier conditions will prevail. Under such conditions, it is good to carry the seedlings around in buckets of water to keep them hydrated. This will lower the stress on the seedlings. It is wise to stop planting when conditions get too hot or windy. It serves no purpose to plant seedlings under dry windy conditions; this will only yield many dead trees within a matter of months.

One of the best indicators of poor planting conditions is if the soil in the trenches starts to dry rapidly within 15 min or less after the trench is dug. Under ideal conditions, there will more be than enough planters being supplied with seedlings to keep up with the bulldozer-trencher. The supervisor of the planting operation should slow down or stop the bulldozer-trencher so that the seedlings are always being planted into moist soil.

Planting procedures. Seedlings with roots should be planted into deep holes and then covered with moist soil. The sandy soil should be compressed lightly with the toe to remove air pockets. Compacting the soil is not a good practice. Given the nature of these areas with dunes everywhere, the wind will fill in the trench within weeks. It is good to get the base of the root system down as deep as possible, which is about 1 m (1.1 yd) from the soil surface. It is common to have 50 cm (19.7 in) of stem sticking out of the ground. In some cases, it is fine to get cuttings with no roots 70 cm (27.6 in) down into the ground, with 10 cm (3.9 in) above the sand. Key to success is ensuring that there are no air pockets around the stem and there is good soil-stem contact.

The critical secret to success in this planting technique is planting the seedlings into moist soil and covering the hole with moist soil. The deeper the cutting goes into moist soil, the higher the odds of success a year later. Root access to water is critical. Given the harsh conditions of this kind of desert, it is easy to see why presoaking seedlings helps to keep them hydrated long enough to produce new roots and access soil moisture.

There have been cases where, due to mishandling, the top of the seedlings died back because the top of the seedling could not get enough water but, due to deep planting and access to soil moisture, the living root system was able to regenerate a top. Although a year of growth was lost, the seedlings lived and continued to grow. The timing of planting in relation to trench making, the level of soil moisture, and the hydration of the seedling all interact to determine the degree of success.

Monumenting and monitoring. Monumenting is the placing of permanent plot markers at the corners of planting areas in order to identify planting location. Monumenting allows accurate relocation of the plots in the future. Typical markers are PVC, copper-treated wooden posts, or cement or metal posts. The markers are often buried 60 cm (23.6 in) deep and stick up ~90 to 120 cm (1–1.3 yd) out of the ground. A thick aluminum metal tag with identifying information is attached to the post.

Although often overlooked as unimportant, the use of permanent plot markers is critical to tracking and determining long-term success. A map and logbook must be kept noting the location of the plot boundaries, along with information on species, type of stock planted, site and weather conditions at planting, and the date of planting. It is also wise to determine the Global Positioning System locations of the permanent plot markers.

Monitoring the plots is important to determining the survival and the growth rates of the seedlings. In order to track seedling growth, each seedling must be given a specific location number that identifies the planting location and the tree number. For large plantings, it is best to break the area up into 100- to 400-tree blocks. The area planted would have an area number or name with numerous blocks. A decision can be made to put metal tags on each tree or to tag only tree 1 and every 10^{th} tree, such as 1, 10, 20, and so forth.

Within 30 d of planting, every tree should be measured for ground line diameter to the nearest millimeter (0.04 in). Height to the nearest centimeter (0.4 in) should be measured from ground line to the terminal bud. If the tree is drooping because of wind or the like, the height should be measured to the highest point above ground line. Groundline diameter and height of each tree should be remeasured in the fall at the end of the first growing season and again each fall for the next 5 yr.

Survival can be determined by counting the missing or dead trees. At the time of each measurement it is common to record other information, such as seedling damage due to insects, disease, or farm animals. If the seedling shows leaf chlorosis (yellowing), that should be recorded. Did the seedling suffer top dieback and then resprout? Is the seedling multiple topped? Is there more than one shoot coming out of the ground? In most cases, those measuring the seedlings will put specific comments next to each seedling's data entry so that its progress can be tracked over multiple years. It is good to make up data sheets with various typical options than can be marked with a 0 or a 1 to denote condition.

After the data have been collected, they must be analyzed to determine planting success and to help modify less successful practices.

Conclusions

Long-term success is possible and has been demonstrated in the Kulun Qi area. What is required is a long-term, sustained effort to implement successful planting practices that coordinate the growing and lifting of seedlings in the nursery with outplanting in the field. The unique harsh conditions create special challenges unlike anywhere else on earth. Great attention to detail must be considered in every procedure and practice.

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Germinating Five Forest Tree Species Native to the Virgin Islands

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Abstract

The scarcity of native trees in production at nurseries of the U.S. Virgin Islands is due in part to the lack of published seed and germination data. To address this, we provide descriptions for five trees that are native to the Virgin Islands and have production potential: wild cinnamon [*Canella winterana* L. (Gaertn)], coco plum (*Chrysobalanus icaco* L.), lignum vitae (*Guaiacum officinale* L.), locust (*Hymenaea courbaril* L.), and ironwood [*Krugiodendron ferreum* Vahl (Urban)]. We developed baseline fruit and seed data and tested the effect of three pregerminative treatments on the seeds: 24-h water soak, boiling water, and 1-h gibberellic acid (GA_3). Seed collection times, fruit and seed weight, time to germination, and expected rates are given. Treatments affected germination in all species except *H. courbaril*, which germinated well with all treatments and the control. All species except *C. winterana* germinated above 70 percent under at least one treatment.

Introduction

There is a growing consensus among both ecologists and urban foresters that using native flora in new plantings is desirable. Exotic plant species represent one of the greatest threats to global biodiversity (Vitousek and others 1997), and the threat is worsening (Mack and others 2000). Invasive or benign, exotic species are now ubiquitous in most of the world's habitats and are costly and difficult to remove (Baskin, 2002). They will always be ecologically significant (Lugo and Helmer 2004). Using native plants reduces the risks inherent with introducing new organisms. Some frequently cited advantages for utilizing native plants include the preservation of genetic diversity (Ewel and Putz 2004), their adaptation to local climate and soil (Parrotta and others 1997), beneficial wildlife interactions (Martinez and Howe 2003), and others.

In the U.S. Virgin Islands, territorial agencies and nonprofit organizations have jointly compiled detailed lists of native trees recommended for both urban forestry and forest restoration (O'Reilly 2002; Daley and Zimmerman 2004). There are, however, several practical impediments to increased utilization of native plant species; primarily, the plants are generally not available in nurseries. This is especially true throughout the Caribbean (Overton and others, in press). A general lack of published germination information may be partially to blame for the absence of many native plants from nurseries.

This paper provides information that will facilitate the production of five Virgin Islands native plants by public and private nurseries. We selected species previously identified as suitable to both ecological and urban forestry plantings. For each taxon, a brief description of the plant and its range, together with data on seed collection time, fruit weight, number of seed per fruit, and seed weight, is provided. We present germination rates for three pregerminative seed treatments for each species and the length of time required for germination. This information should facilitate collection and handling of native seeds and production of native forest tree seedlings in the territory.

Materials and Methods

Five tree species native to the U.S. Virgin Islands were examined in this study: wild cinnamon [*Canella winterana* L. (Gaertn)], coco plum (*Chrysobalanus icaco* L.), lignum vitae (*Guaiacum officinale* L.), locust (*Hymenaea courbaril* L.), and ironwood [*Krugiodendron ferreum* Vahl (Urban)]. They were chosen for their potential use in urban forestry systems and because of their local scarcity. Seed collection times were documented for each species during 30 mo, starting in August 1999. Seeds were collected along an island-wide transect on St. Croix that included ridge tops, sandy beaches, and the elevation gradient in between. Fruit was collected from multiple trees in multiple locations whenever possible. Collection times are listed in table 1.

All seed germination was conducted at the Agriculture Experiment Station at the St. Croix campus of the University of the Virgin Islands. Upon collection, the fruit were cleaned, counted, and weighed. Seeds were then removed

Table 1. Fruit and seed data for each species.

Tree	Fruit kg^{-1}	Seeds fruit^{-1} [mean (observed range)]	Seed kg^{-1}	Seed collection time
C. winterana	2,324	1.74 (1 or 2)	22,000	Sep–Nov
C. icaco	820	1	446	Aug–Dec
G. officinale	1,390	1.70 (1 or 2)	3,220	Aug and Mar*
H. courbaril	11.3	8.51 (4–12)	270	Aug and Mar*
K. ferreum	2,050	1	11,100	Aug–Oct

*Trees tend to have two fruiting periods per year.

from their fruit, rinsed clean, counted, and weighed. Pregerminative treatments were conducted within 24 hours of collection. The handling procedure varied slightly depending on the size and texture of the fruit, but all seeds were free of fruit material and undamaged at the time of treatment. Only fresh seeds from mature fruit were used.

The pregerminative seed treatments were a 24-h water soak at room temperature (soaking); 30-s dip in 100 °C water, followed by cooling under running water (boiling); 1-h soak in a 2,000 ppm aqueous solution of gibberellic acid (GA_3); and no pretreatment (control). The three pregerminative seed treatments and the control were applied to all species, with 20 seeds per treatment. Preliminary analysis detected no significant date effect, so for each taxon, we treated experiments on different dates as true replications. There were at least five replications per treatment per species.

Treated seeds were sown in trays with potting soil and kept moist. Seed germination data were collected daily and expressed as a percentage once germination was completed. The germination start time is the average time elapsed between seed treatment and emergence of a seedling. Percent germination data were inverse sine transformed before analysis. ANOVA was conducted and the means for species with significant differences among treatments were compared by Least Significant Difference (SAS version 8, SAS Institute, Cary, NC).

Results

Canella winterana. This is a small tree between 7 and 10 m (23–32 ft.) tall that has a dense, dark green crown and a smooth to warty gray bark. The petite, dark, red to purple flowers are rich with nectar. Small round, red berries contain one or two seeds and a sticky resin (figure 1). Leaves and bark are said to be medicinal; the fruits, when collected green and dried, are reported to be hot like black pepper (Little and Wadsworth 1964). Timber is blackish and extremely hard (Timyan 1996). The tree is found primarily in dry sandy areas from south Florida through the Greater Antilles and into the Lesser Antilles to St. Lucia and Barbados. In St. Croix, only isolated examples remain in the wild, but the tree could do well as an ornamental (Jones 1995).

Fruits were collected from the west of St. Croix in September and October 1999 and September and November 2000. The seeds were easily removed from the berries and the clear, sticky resin was rinsed off before treatment. There are 2,324 fruits kg^{-1} (1,000 lb^{-1}), with an average of 1.74 seeds per fruit and 22,000 seeds kg^{-1} (9,285 lb^{-1}) (table 1).

Germination, which began at 30 d, was sporadic and concluded after 120 d. No treatment successfully initiated early germination. The boiling water treatment was ineffective, killing all seeds in all five replications (table 2). The GA_3 and control treatments were the most successful,

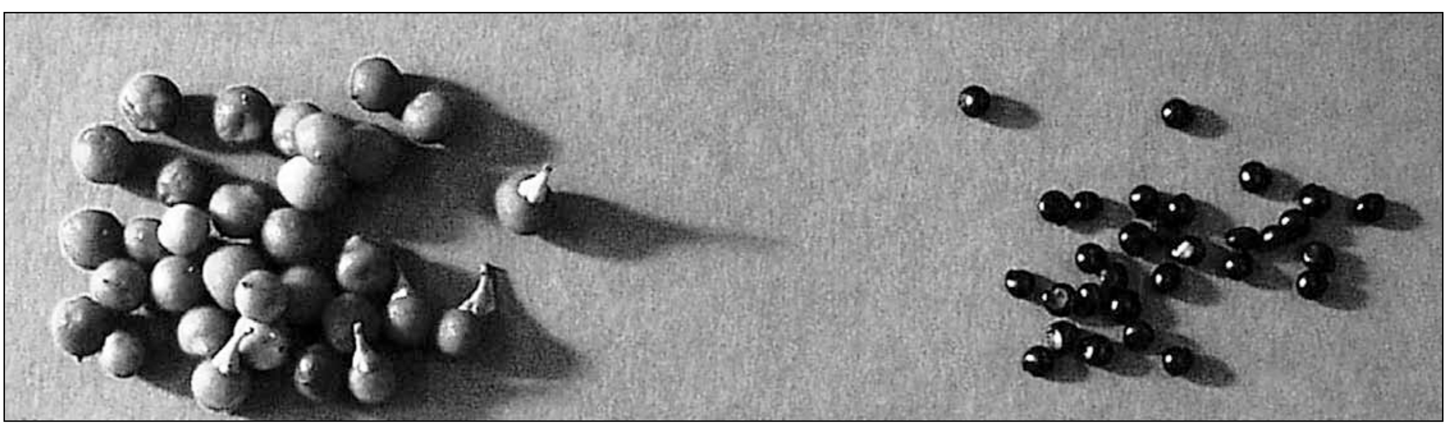

Figure 1. Mature fruit (left) and cleaned seeds (right) from wild cinnamon (*Canella winterana*).

Table 2. Average germination percentage of five tree species after seed pretreatment.

Pretreatment	*C. winterana*	*C. icaco*[1]	*G. officinale*[2]	*H. courbaril*	*K. ferreum*[2]
Water soak	6ab	91a	46ab	64	86a
Boiling water	0b	32b	4b	65	0b
GA_3	33a	73a	71a	70	13b
Control	29a	50ab	29b	56	85a

[1] Mean separation by LSD ($p<0.01$)

[2] Mean separation by LSD ($p<0.05$)

though both treatments produced <30 percent germination. Therefore, no treatment is recommended for this species. Low germination rates should be anticipated and sufficient seeds should be collected to compensate.

Chrysobalanus icaco. Low-growing and multistemmed, this shrubby tree reaches 3–6 m (9.8–19.7 ft) in height. It has a canopy of dark green, thick, leathery leaves. It is found primarily at sea level on sandy beaches. Flowers are small and grow in clusters. The edible, round fruit is about 5 cm (1.97 in) in diameter, containing a sweet, white, meaty flesh around one large, woody seed. The Virgin Islands variety has a white to pink skin; those from Florida and the rest of the Lesser Antilles are dark purple and smaller. This species' natural range is from southern Florida through most Caribbean islands and along the coastline from Mexico to Brazil and Ecuador (Little and others 1974).

Fruiting season varies annually. We collected fruit in September 1999 and August, November, and December 2001. Ripe fruit was taken directly from the tree or freshly fallen fruit was collected from the ground. The seed was cleaned by floating the fruit in water and then scraping on a screen to remove the flesh. Overall, the four collections averaged 82.7 fruit kg^{-1} (37.2 lb^{-1}) and 446 seeds kg^{-1} (202 lb^{-1}).

Germination (figure 2) began between 42 and 60 d and was considered complete by 100 d. None of the treatments significantly reduced germination start time or germination period. Ten percent of germinated seeds produced two individual plants. Soaking and GA_3 (91 and 73 percent, respectively) were significantly more effective than boiling (32 percent) (table 2). The difference between the soaking and control (50 percent) treatment means was not significant, largely due to high variability between replications. Nonetheless, the numerically higher rate and slightly improved germination start time represent a real improvement, and we recommend the soaking treatment for this species.

Guaiacum officinale. This is a small to medium-sized, multistemmed tree reaching a maximum height of 10 m (figure 3). It has a dense, rounded crown of dark green leaves. The bark is light brown, mottled and peeling. Masses of light to dark blue flowers bloom at various times during the year in different parts of the same tree. Fruit are flat, yellow, heart-shaped capsules, containing one or two seeds covered in a bright red aril, which are released at maturity. Its native range extends through the Greater and Lesser Antilles, Panama, Colombia, and Venezuela, though it is planted as an ornamental through much of tropical America (Little and Wadsworth 1964). It is the national

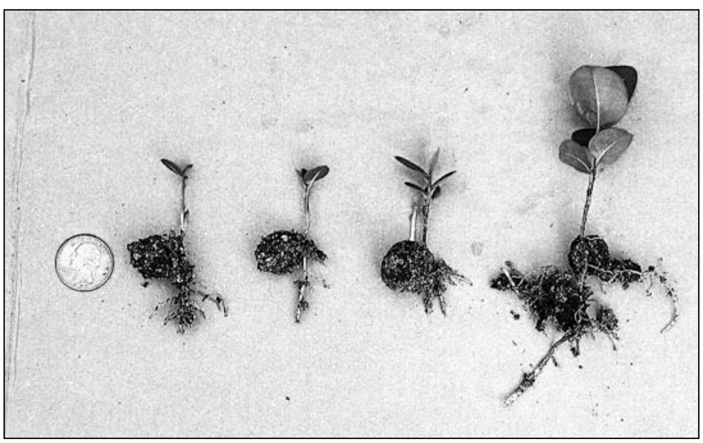

Figure 2. Early development of coco-plum (*Chrysobalanus icaco*) seedlings. Ten percent of the seeds were polyembryonic, which can be noted in the second plant from the right.

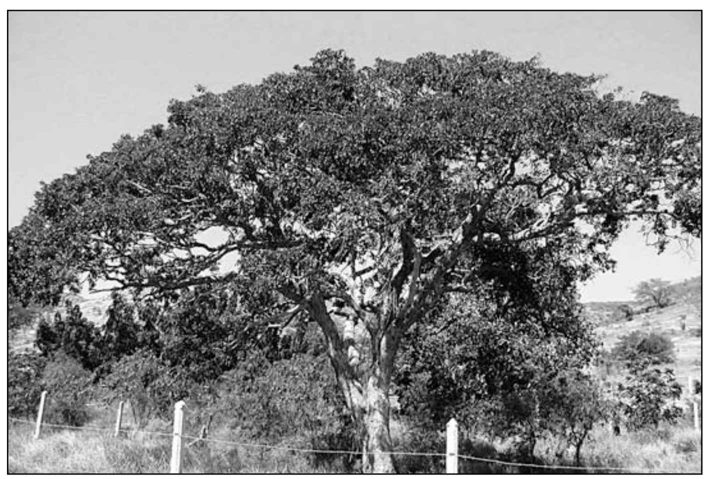

Figure 3. This lignum vitae (*Guaiacum officinale*) tree is estimated to be 150 years old and is an iconic hardwood of the Caribbean dry forest.

flower of Jamaica and appears on the Virgin Islands list of endangered species (Gibney and others 1991). This species readily self-propagates in the wild, grows well under shade, and is extremely resistant to drought, which have all contributed to its recent spread in Forest Service Estate St. Thomas property in St. Croix and many areas of the drier east side of St. Croix.

Seeds were collected in August 1999 and March 2000 and 2001, although they are abundantly available at many other times of the year on St. Croix. Fresh seeds can be collected from the ground around the tree or taken from the tree once the seed is released from the fruit. Seeds were cleaned of their fleshy arils by a brief soaking in water and rinsing under running water, leaving a black, porous, oval seed. Five collections averaged 1,390 fruit kg^{-1} (630 lb^{-1}) and 3,200 seeds kg^{-1} (1,460 lb^{-1}) similar to that reported by Betancourt (1987) and Francis (1993).

Germination began in 15 to 20 d and concluded in 5 wk. The GA_3 treatment was significantly better than both boiling and control. The boiling treatment showed a negative effect, resulting in 4 percent germination, whereas the control produced 29 percent. The control rate is half of the 60 percent reported for fresh seeds in Cuba (Betancourt 1987). We recommend GA_3, which resulted in 73-percent germination, for this species. This treatment had a higher germination percentage in 5 wk than previously reported rates of 50 percent germination over 6 mos (Francis 1998; 2002). Rapid, even germination at high rates with this treatment makes this species well suited to commercial production by nurseries.

Hymenaea courbaril. This medium to large, spreading, usually evergreen tree reaches heights of 15 to 20 m (49.21–65.62 ft) and stem diameter of 1 m (3.28 ft). It has

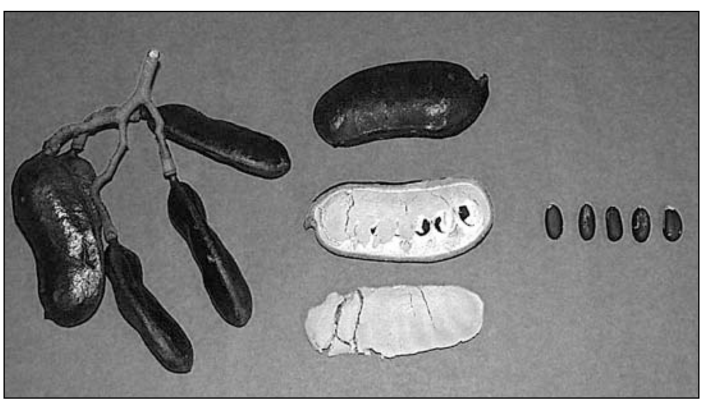

Figure 4. From left to right, mature locust (*Hymanaea courbaril*) fruit, cross-sectioned pods with seeds visible within the pulp and the cleaned seeds extracted. The strong-smelling pulp earns it the name “stinking toe” in the Virgin Islands.

smooth, gray bark and produces large, woody fruit pods [figure 4]. The sweet, edible, but strong-smelling pulp inside the fruit earns it the name ‘stinking toe’ in the Virgin Islands. It produces a durable, heavy, hard, highly valuable wood for timber (Timyan 1996). Its native range extends from southern Mexico through Central America and south to Peru, Brazil, and Bolivia (Little and Wadsworth 1964). In the Virgin Islands, the fruit bat (*Brachyphylla cavernarum)* feeds on the nectar of the flowers (Gary Kwiecinski, personal communication).

We collected seeds of this species in March and August of 2000 and 2001. Ripe brown fruit were cut from the tree canopies with a pole-pruner and opened with a hammer. Average weight for the pods was 88 g (3.1 oz) or 11.4 fruit kg^{-1} (5.16 lb^{-1}) with 8.5 seeds pod^{-1} and 270.3 seeds kg^{-1} (120.2 lb^{-1}).

Germination began in 20 d for the control and in 14 d for the three pregerminative treatments. Both scarification and soaking in sulfuric acid have previously been shown to increase germination percentages and reduce germination time (Francis 1990; Vozzo 2002). Other studies suggest manual scarification and several other treatments made germination more uniform and improved rates, though they did not determine if the improvements were significant (CATIE 1999). Our research supports the previous findings, as rate and speed of germination were enhanced by all three treatments, relative to control. Although numerically greater, these differences were not significant. Therefore, a pregerminative treatment may be used to achieve only slight improvements in germination rate and time. This was the only species of the five that was not negatively affected by the boiling treatment.

Krugiodendron ferreum. This small, multistemmed tree grows to 6–8 m (19.69–26.25 ft) tall. It has a dense crown of leaves, which are reddish when immature, turning dark and shiny green. The bark is gray and smooth, becoming scaly with age. Flowers are inconspicuous, yellow–green, and lacking petals; they appear in clusters intermittently throughout the year. Berry-like fruits are elliptical, purple to black, and contain one seed. Its native range spans from southern Florida through the Greater and Lesser Antilles to St. Vincent and Curacao (Little and Wadsworth, 1964). Distribution on St. Croix is mostly in the moister west end of the island; it is fairly common along some road sides. Average fruit weight is 0.45 g (0.016 oz) each, or 2,054.7 kg^{-1} (932.4 lb^{-1}) and 11,100 seeds kg^{-1}(5,038 lb^{-1}).

Fruits for this study were collected in the northwest of St. Croix in August and October 1999 and November 2000. Ripe fruit was taken directly from the tree. The seeds are easily removed from the soft, juicy drupes by squeezing them out and rinsing away the remaining pulp. Germination (figure 5) began after 14 d and finished in 4 wk. Soaking and control treatments were significantly better than boiling or GA_3. Not a single seed in any replication from the boiling water treatment germinated, and GA_3 had only 13 percent germination. Therefore, no treatment is recommended to increase germination.

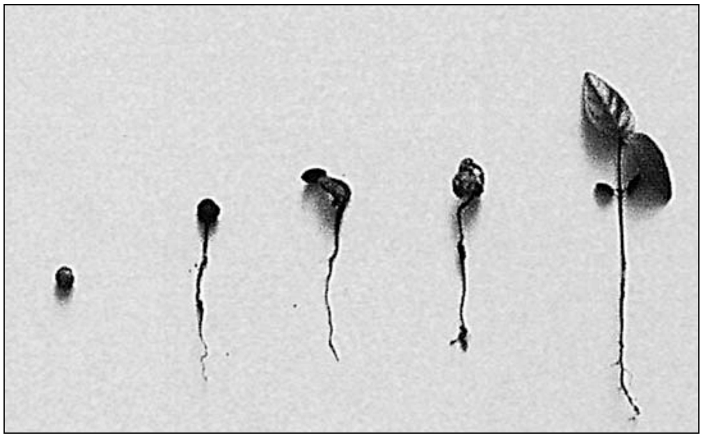

Figure 5. Stages of seed germination for the Virgin Island's ironwood (*Krugiodendron ferreum*).

Discussion

We know of no published germination rates for three of the species (*C. winterana*, *C. icaco*, and *K. ferreum*). Several organizations in the U.S. Virgin Islands have identified these species as desirable for use in reforestation and urban and community forestry. The sparse local distributions of all these species make seed collection difficult during parts or all times of the year. Limited distribution and a low germination rate (below 30 percent) make *C. winterana* the only tree of the five that remains problematic to reproduce in larger quantities. The other four species in this study have more extensive populations on St. Croix and germination rates ≥70 percent, making large-scale or commercial production possible.

Numerically, GA_3 treatment achieved the highest germination rates in *C. winterana*, *G. officinale* and *H. courbaril*. Soaking was highest for *C. icaco* and *K. ferreum*. In the case of *H. courbaril*, all three treatments made germination more rapid. These increases did not represent statistically significant improvements over other treatments, however. In fact, a pregerminative treatment significantly improved germination, relative to control, only for *G. officinale*. Although a pregerminative treatment is not required to germinate these species, we observed the higher germination percentages to be a real benefit, especially when seed sources are limited. Additionally, in treated seed groups a flush of seeds frequently germinated within a day or two of one another. Our experience in the greenhouse was that seedlings from treated seeds were more uniformly sized, making them easier to transplant.

Conclusions

Throughout the United States and the Caribbean, there is an increasing trend toward using native plants in landscapes. Our experience with nursery operators in St. Croix and elsewhere indicates their first obstacle in growing more native plant material is not knowing where and when to collect seeds and how to handle them. These replicated experiments provide growers with a proven method and expected germination rates for these taxa. A high degree of variability is inherent whenever working with seeds from wild species. This can be minimized by following the appropriate standardized protocol described in this paper. In many cases, germination can be further improved by using pregerminative treatments. Applying this data will streamline the seed collection and germination process for large and small producers alike.

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Reforestation Success in Central México: Factors Determining Survival and Early Growth

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Abstract

Successful reforestation programs are requisite components of any forest industry; failure to establish new forests can lead to deforestation. The objective of this project was to examine factors influencing reforestation success in Central México, encompassing the Federal District and State of México. Seven plantations, established in 1995 with five conifer species, were monitored for 2 yr. Survival after 2 yr ranged from 15 percent to 86 percent. Most of the mortality was related to human activities, including fire, livestock grazing, and agricultural cultivation. Nevertheless, seedling quality was an important component of both seedling survival and subsequent growth. A minimum seedling diameter of 4 mm (0.16 in.) is required for adequate survival, but the target seedling diameter should be 6 mm (0.25 in.) for *Cupressus* and 8 mm (0.32 in.) for *Pinus* to ensure highest survival and growth.

El éxito de la reforestación en la Región Central de México: Factores que determinan la sobrevivencia y crecimiento temprano de las especies

Resumen

El éxito de los programas de reforestación es un componente indispensable en la industria forestal, ya que representa una fuente importante de abastecimiento de materia prima, por lo que su fracaso ocasiona problemas económicos graves; además del impacto negativo que sobre los ecosistemas tiene la pérdida de la cobertura vegetal (desforestación). En el presente estudio, se analizaron los factores que determinan la sobrevivencia y crecimiento temprano de cinco especies de coníferas, mediante dos años de monitoreo en siete sitios de plantación localizados en el Valle y Estado de México en 1995. Del segundo año de evaluación, la sobrevivencia de la planta fué del 15 al 86 por ciento. La mayor mortandad se relacionó con actividades humanas como son: quemas no controladas y cambios en el uso del suelo con fines agrícolas y pecuarios. Un factor importante tanto para la sobrevivencia, como para el crecimiento de las plantas en campo fue la calidad de la planta producida en los viveros. La sobrevivencia óptima de la planta se presentó en individuos con diámetros de tallo superiores a 4 mm (0.16 in.). Sin embargo, para asegurar la mayor sobrevivencia y crecimiento, se recomienda que el diámetro de plántula ideal para *Cupressus* sea de 6 mm (0.25 in.) y para *Pinus* sp. de 8 mm (0.32 in.).

Introduction

México is the 14th largest country in terms of land mass and forest cover with nearly 142 million ha (355 million ac), 55.3 million (138 million ac) of which are covered with forests or woodlands (SEMARNAP 1998a). Unfortunately, 250,000 to 600,000 ha (625,000 to 1,500,000 ac) of forest land are lost every year to deforestation (WRI 1994). A recent national inventory (SEMARNAP 1998b) estimated 25.4 million ha (63.5 million ac), or nearly 50 percent of the forest land, have suffered some degradation through conversion to agriculture, illegal harvesting, or other changes in land use. Greater reforestation efforts are needed to offset deforestation (Torres and Magaña 2001).

Federal, state, and community forestry programs produce nearly 400 million seedlings each year (Anonymous 1997), most in polybags filled with forest soil or a mixture of forest soil and sand or aged sawdust. Seedlings are grown for 8–20 mo, depending on species and the reforestation program, before outplanting during the rainy season (late May–September). Occasionally, seedlings may be held over for an additional year if seedlings are too small or if planting crews or sites are unavailable. In some cases, these holdover trees may be transplanted to a larger polybag if resources allow.

Until recently, there was little information on the survival of seedlings planted in reforestation programs in México. Generally, survival has averaged less than 50 percent throughout the country (Anonymous 1997); a recent national survey of 1998 reforestation activities found survival averaged 47 percent (Bello and Cibrián 2000), ranging from 39 percent for seedlings supplied by state nurseries to 67 percent for seedlings grown by social organizations. Even within a region, survival can vary. Survival of various conifers in the state of Michoacan averaged 34 percent (Madrigal and Piedad Garcia 2000), *Abies religiosa* in the state of Hidalgo averaged 40 percent, and conifers in the Federal District of México averaged 48 percent (Sierra and Rodriguez 1991).

These survival rates are low compared to those in the United States, where survival averages over 70 percent with a much larger reforestation program (Weaver and others 1981**)**. Furthermore, individual companies can have survival consistently approaching 90 percent (South and Mitchell 1999). Unfortunately, these statistics on Mexico's reforestation, while providing an indication of survival, include little information on causes or timing of mortality. For example, Sierra and Rodriguez (1991) did not attribute any mortality to poor seedling quality. Most mortality was attributed to “drought” (13 percent) or “unknown” (10 percent), both of which could be significantly related to seedling or planting quality. Bello and Cibrián (2000) attributed 22 percent of mortality to “seedling quality” (undefined) and 7 percent to “planting quality.” However, 29 percent of mortality was attributed to “drought.”

A better understanding of causes of plantation mortality could lead to improved nursery production practices and reforestation practices (Randall and Johnson 1998). The objective of this project was to determine the causes of mortality in recently planted plantations in Central México.

Materials and Methods

The study sites were located in the Federal District and the state of México around México City at elevations above 2,000 m (6,550 ft). These two governmental entities planted over 70 million seedlings in 1995–1996 (Anonymous 1997). Established plantations in each region were evaluated during the monsoon season (June–September 1995), which corresponds to the planting season in México.

Experimental units consisted of 3–5 circular plots [0.005–0.01 ha (0.0125-0.0250 ac)] per plantation (Neumann and Landis 1995). For convenience in reading, species used and plot details are given in the Results section following. Seedlings were identified and height and groundline diameter measured. Size (height and ground line diameter) after planting and planting depth and firmness of each seedling were evaluated. The closest seedling to the north side of the plot was excavated for assessment of root quality (planting depth, number of laterals, and taproot deformation [either by transplanting in the nursery or outplanting in the field]). The plots were revisited 3–5 times over the next 26 months. Causes of mortality and changes in vigor and size were recorded.

Results and Discussion

***Abies religiosa* (oyamel).** The San Miguel Balderas plantation in the state of México was a privately owned pasture on about 15 percent slope. *Abies religiosa* seedlings were grown in large polybags [12 cm × 35 cm (4.75 in × 13.8 in)] for 2 yr and planted for Christmas tree production. Seedlings were planted on 1.5 m × 1.5 m (5 ft × 5 ft) spacing about July 6, 1995, and five survival monitoring plots were established on July 27, 1995. Four of the five excavated seedlings had evidence of new root growth, but one seedling (20 percent) had a poor rootball, and four (80 percent) were loosely planted. There also was evidence of grubs in one rootball (20 percent).

In spite of loose planting, survival was 98 percent after 4 mo, but after 26 mo it was only 15 percent. Three of the plots were damaged by fire (arson), although only one plot was actually destroyed by fire (table 1). Two of the burned plots, plus a third plot, were plowed and converted to agriculture (the previous land use). The remaining plot appeared healthy, but growth was poor, averaging less than 1 cm (0.4 in) of new growth after 26 mo. There was a weak positive relationship (r^2=0.55) between diameter growth and height growth (data not shown). Seedlings that shrunk in diameter suffered shoot dieback, while those with diameter growth also exhibited height growth. The poor growth may have been due to the loose planting.

***Cupressus lindleyii* (cedro blanco).** *Loma de Medio Predio plantation.* The Loma de Medio Predio plantation in the state of México was a privately owned pasture on 0 percent slope. One-year-old seedlings of *C. lindleyii* were grown in polybags [9 cm × 25 cm (3.5 in × 10 in)], and planted for commercial post production. Seedlings were planted about July 25, 1995, on 1 m × 1 m (3.3 ft × 3.3 ft) spacing. Three survival monitoring plots were established on July 26, 1995. Weeds were controlled manually at least once during the subsequent year.

Seedlings were well planted with new root growth evident. Smaller seedlings usually were missing the lower one-half of the rootball. Survival was 97 percent after 4 mo and 86 percent after 26 mo (table 1). The major cause of mortality was rabbit damage (6 percent). Insect damage was common on most seedlings, evidenced by lesions on the root collar

Table 1. Initial seedling morphology and causes of mortality (mean ± standard deviation) for the seven plantations evaluated in the Valle de México.

Species	*A. religiosa*	*C. lindleyii*		*P. ayacahuite*		*P. patula*	*P. pseudostrobus*
Plantation	San Miguel Balderas	Loma de Medio Predio	San Bartolo Ameyalco	San Banabé Ocotepec	Rancho Don Nati	Los Mena	La Esperanza
Height (cm)							
Initial	44.5 ± 10.8	33.4 ± 9.1	33.0 ± 13.2	41.4 ± 9.9	28.5 ± 2.8	32.0 ± 11.8	21.5 ± 6.4
Final	46.8 ± 11.7	131.0 ± 21.7	105.7 ± 26.3	54.7 ± 13.9	99.4 ± 9.0	42.7	24.5 ± 10.3
Diameter (mm)							
Initial	7.1 ± 1.7	3.9 ± 0.8	3.8 ± 1.2	6.6 ± 1.4	9.7 ± 0.5	5.0 ± 0.7	6.3 ± 1.5
Final	11.7 ± 1.1	21.7 ± 1.7	14.8 ± 4.0	12.4 ± 3.0	35.2 ± 3.3	n.m.	6.0 ± 1.8
Survival (%) at							
4 mo	98	97	100	93	95	44	100
10 mo	78	89	92	89	33	33	27
26 mo	15	86	84	67	15	27	n.a.
Mortality (%)							
Seedling quality	1	2.8	10	10	0	0	3
Planting quality	1	2.8	0	9	0	35	3
Rodent damage	0	5.6	0	4	8	7	0
Insect damage	0	2.8	0	1	1	0	0
Grazing damage	0	0	0	0	35	0	0
Fire	20	0	0	0	0	0	67
Cultivation	63	0	0	0	0	0	0
Fertilizer damage	n.a.	0	n.a.	n.a.	n.a.	7	n.a.
Unknown	0	0	6	9	41	24	0

n.a.=not applicable.
n.m.=not measured.

and stem. Occasionally, trees were girdled completely below the root collar, resulting in 3 percent mortality. Nevertheless, survival and growth were excellent. Seedlings averaged 131 cm (4.3 ft) in height after 26 mo. There was no correlation between initial seedling size and subsequent growth.

San Bartolo Ameyalco ejido. The San Bartolo Ameyalco ejido in the Federal District planted *C. lindleyi* for erosion control. Seedlings were grown in polybags [6 cm × 25 cm (2.4 in × 10 in)], and planted on 2 m × 2 m (6.5 ft × 6.6 ft) spacing under a mature pine-fir forest on July 25, 1995. Three survival monitoring plots were established. Seedlings were well planted.

Survival was 100 percent after 4 mo and 84 percent after 26 mo. Seedling quality (small diameter) accounted for most of the mortality (table 1). Growth was excellent, and final height averaged 106 cm (3.5 ft) after 26 mo. Final survival and height were correlated with initial seedling diameter (figure 1A). Seedlings with at least 4 mm (0.16 in) diameter had excellent survival, but growth continued to increase with increasing diameter for seedlings with an initial diameter of 8 mm (0.32 in).

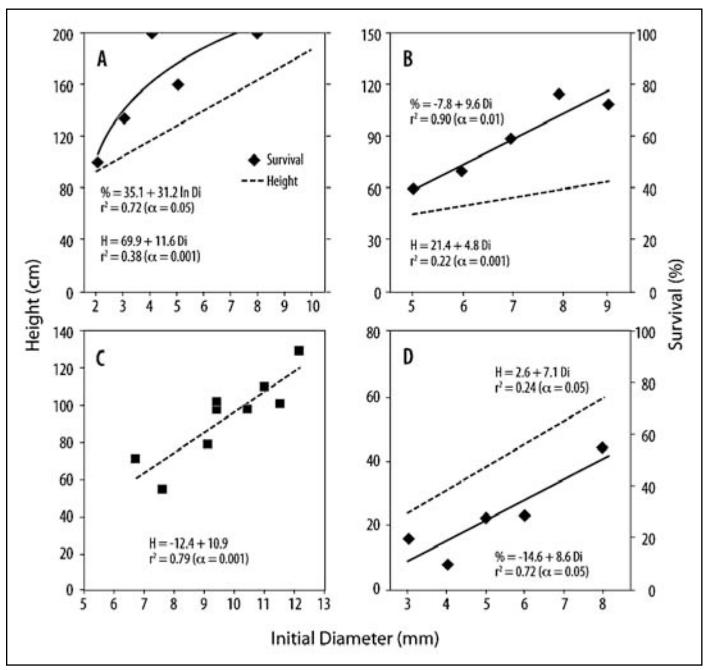

Figure 1. Relationship between initial seedling diameter and survival and height after 26 mo of (A) *Cupressus lindleyii* at San Bartolo Ameyalco, (B) *Pinus ayacahuite* v. *veitchii* at San Bernabé Ocotepec, (C) *Pinus ayacahuite* v. *veitchii* at Rancho Don Nati (height only), and (D) *Pinus patula* at Los Mena.

***Pinus ayacahuite* v. *veitchii* (generic common names, pino or ocote).** *San Bernabé Ocotepec ejido*. San Bernabé Ocotepec ejido in the Federal District planted *Pinus ayacahuite* v. *veitchii* seedlings for erosion control. Seedlings were grown in 6 cm × 25 cm (2.4 in × 10 in) polybags and outplanted at 2 m × 3 m (6.5 ft × 9.8 ft) spacing under mature pine forest. Seedlings were planted about July 25, 1995, and three survival monitoring plots were established. Seedlings were well planted.

Survival was 93 percent after 4 mo, but only 67 percent after 26 mo. Seedling and planting quality were the major causes of mortality (table 1). Growth after 26 mo was poor, averaging 11 cm (4.3 in). This is a drier site than San Bartolo Ameyalco, which was planted with *C. lindleyii*, and seedling establishment may have been more difficult under a mature forest. Survival and growth were linearly correlated with initial seedling diameter (figure 1B). Seedlings larger than 7 mm had the best survival and growth.

Rancho Don Nati. Rancho Don Nati was a privately owned pasture in the state of México on about 25 percent slope. The area was grazed heavily by goats at time of planting in July 1995. Seedlings were grown in large polybags [12 cm × 35 cm high (4.75 in × 13.8 in)], and planted at 1.5 m × 1.5 m (5 ft × 5 ft) spacing for Christmas tree production. Five survival monitoring plots were established on July 24, 1995. Most of the excavated seedlings had evidence of new root growth (60 percent) and grubs in the rootballs (80 percent). One seedling (20 percent) was planted shallowly, and another (20 percent) was barerooted due to small seedling size. There was no evidence of grubs on one plot, which was a steep, rocky site.

Survival was 95 percent after 3 mo, but only 15 percent after 24 mo. The major cause of mortality was grazing by goats (table 1). Only Rep 5, planted in steep, rocky soil, had surviving seedlings (77 percent). This site had a large percentage of "unknown" mortality (41 percent) that may be attributable to a combination of freeze damage, heavy grub infestation in the rootball, and grazing. Most of the excavated seedlings had evidence of root feeding, and most planting holes had grubs present. The origin of the grubs is not known. Seedling growth, but not survival, was correlated with initial seedling diameter (figure 1C).

***Pinus patula*.** Los Mena was a privately owned pasture in the state of México on 0-percent slope. Two-year-old *Pinus patula* seedlings were planted on 2 m × 3 m (6.5 ft × 9.8 ft) spacing for pole production. Seedlings were grown in gussetted 9 cm × 25 cm (3.5 in × 10 in) polybags, resulting in an open bag diameter of about 10 cm (3.9 in), and planted July 1995. Each seedling received about 5 g (0.2 oz) surface-applied urea immediately after planting. Five survival monitoring plots were established on July 24, 1995. Most (3 of 5) of the excavated seedlings had evidence of shallow planting, and 20 percent had poor rootballs. There also was evidence of grubs in one rootball (20 percent).

Survival was 44 percent after 3 mo, and only 27 percent after 24 mo. Major causes of mortality were shallow planting and fertilizer damage at time of planting (table 1). Grazing caused an additional 7 percent mortality, and 24 percent was due to "unknown" causes (possibly related to planting quality). Surviving seedlings initially suffered 2 cm (0.8 in) dieback, which may have been due to fertilizer burn. Both survival and height were positively related to initial seedling diameter (figure 1D).

***Pinus pseudostrobus*.** La Esperanza was a native forest restoration planting following a wildfire on communal property in the state of México. The forest is routinely burned to improve pasture for cattle grazing. *Pinus pseudostrobus* seedlings were planted on 3 m × 3 m (9.8 ft × 9.8 ft) spacing under a mature forest. Seedlings were grown in polybags [6 cm × 25 cm (2.4 in × 10 in)], and planted on July 26, 1995. Three survival monitoring plots were established. All seedlings were planted correctly, but 2/3 of the excavated seedlings only had a partial rootball. Survival was 100 percent after 3 mo, but only 27 percent after 10 mo, as 2/3 of the site was destroyed by fire in April 1996. Height growth of surviving seedlings averaged 3 cm (1.2 in) while diameter shrunk to 6.0 mm (0.24 in), due to heavy grass competition. This site was abandoned after 10 mo.

Factors affecting survival and growth. Only the *Cupressus* plantations had adequate survival (mean = 85 percent). The other plantations averaged only 30 percent. The primary cause of seedling mortality was human activity (figure 2). However, the direct activity varied among plantations (table 1). Fully 67 percent, and possibly as much as 85 percent, of the mortality was attributed to such activities (in decreasing order) as burning, cultivation,

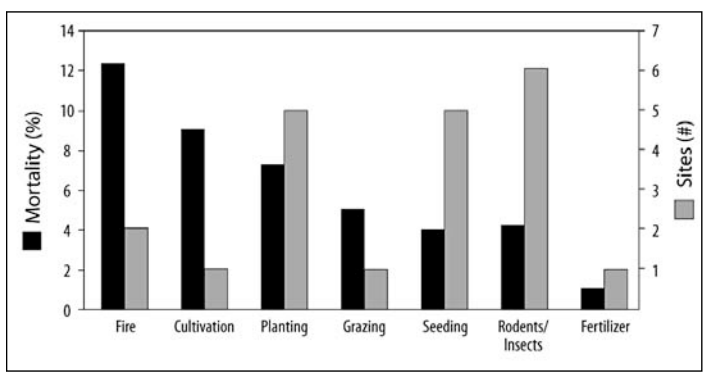

Figure 2. Principal causes of mortality and its frequency on the seven plantations evaluated in the Valle de México and State of México, 1995.

poor planting quality and livestock grazing. Four of the seven plantations were destroyed. The sites that had the best survival and growth were those too steep to support either crop production or grazing. These factors are easily corrected if reforestation becomes a priority for the communities or landowners.

As reforestation becomes a priority for México, land managers must develop minimum size standards for seedling production. As the United States has moved to adopting a minimum diameter of 4 mm, survival has increased. Quality seedlings generally are better suited to withstand the stresses following planting, such as grazing, poor planting, or insect attack. Seedlings with larger diameter at time of planting survived better, regardless of species (figure 3A). Seedlings with initial diameters less than 3 mm had about 40 percent survival, whereas seedlings with diameters larger than 6 mm had over 60 percent survival. These results are similar to findings in the United States with different production systems (Mexal and Landis 1990; Mexal and South 1991).

Seedling growth, like survival, was related to initial seedling diameter (figure 3B). Unlike survival, however, which seemed to be independent of species, species differed in growth response. *Cupressus* grew faster than *Pinus* species. With future growth in mind, 4 mm (0.16 in) should be the minimum standard for seedlings, and efforts should be made to increase seedling diameter to at least 6 mm (0.24 in) for *C. lindleyii* and 8 mm (0.32 in) for *Pinus* sp.

An integrated evaluation of both nurseries and plantations is required before major improvements can be implemented. Evaluating nurseries in isolation (Aldana 2000) is unlikely to result in much improvement in plantation establishment, unless guidelines relating nursery factors to field performance are developed. Even evaluating plantations

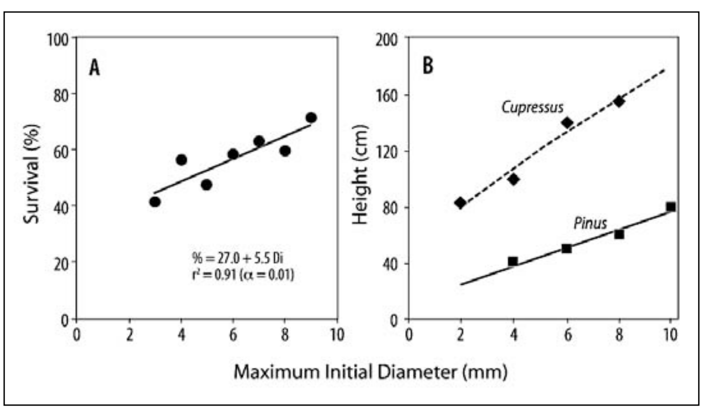

Figure 3. Relationship between initial seedling diameter and (A) survival (*Cupressus* and *Pinus* combined) and (B) final height of *Cupressus lindleyii* and *Pinus* sp. plantations after 26 mo in central México, 1995.

is not beneficial, however, if much time elapses between planting and evaluating. For example, a common cause of mortality in México is "drought" (Bello and Cibrián 2000; Sierra and Rodríguez 1991), but this could easily result from poor seedling quality, loose planting, exposure, or even late planting.

For the most part, polybag production systems have been denigrated (Josiah and Jones 1992), often with a lack of data substantiating the claims of poor performance. Likewise, few data support their continued use. Napier (1985) proposed a target seedling diameter of 3–6 mm (0.12–0.24 in) for conifers in Central America but provided no empirical data relating seedling size to performance. This study indicates polybag production systems can successfully be used to produce conifers for reforestation in México, and it appears that large-diameter seedlings [6 mm (0.24 in) for *C. lindleyii* and 8 mm (0.32 in) for several species of *Pinus*] would provide the greatest potential for success of conifer reforestation.

Polybag systems are not without problems. Typically, the growing medium is forest soil or a mixture of forest soil and sand. Soilless media, humus, compost, or pinebark could be substituted for all or part of the medium. This would reduce weight and destruction caused by soil collection. Often germinants are transplanted (pricked out) into polybags. This can easily result in taproot deformation, which can impact future tree survival and growth. This "problem" is not inherent to polybags and is solved by either direct seeding or careful transplanting. Even if seedlings are transplanted properly, root quality can be affected by lateral roots spiraling around the rootball or the taproot growing out of the polybag into the soil of the nursery bed. The taproot can be pruned by following guidelines to periodically lift the seedlings from the nursery bed. Root spiraling can be minimized by proper timing or, if the seedlings are held too long, by pruning the root prior to transplanting in the field.

This success is critical for México. In 1998, over 5,500 forest fires burned more than 31,000 ha (SEMARNAP 1998a). Unfortunately, reforestation success following these fires is poor (Robles and Angeles 2000) for both seedlings and seeding. Improved seedling production practices are urgently needed. Reforestation can be successful with polybag systems. Limited reforestation resources should not be expended on planting and replanting areas because of poor seedling quality, poor planting supervision, and a lack of commitment to forestry. Improving the quality of the seedlings and protection of reforested areas will reduce wasting valuable resources.

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Container Western White Pine Seedlings: Root Colonization by Fusarium and Cylindrocarpon Species

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Abstract

Healthy-appearing container seedlings of western white pine were sampled for root colonization by potentially pathogenic *Fusarium* and *Cylindrocarpon* spp. at an Idaho forest nursery. Seedlings were sampled monthly for 8 mo with the goal of better understanding epidemiological changes that might occur over time. *Fusarium* spp., especially *F. proliferatum*, were present at relatively high levels throughout the seedling production cycle. *Cylindrocarpon* (mostly *C. destructans*), however, was not detected until seedlings were 18–22 wk old. Root colonization by *Cylindrocarpon* remained much less than that by *Fusarium* spp. Although high levels of *Fusarium* contaminated seeds before sowing, potentially pathogenic species were mostly detected only at low levels. *Cylindrocarpon* spp. were detected infrequently on seeds. Very low levels of root disease occurred during the crop cycle. Good root plug condition was common on sampled seedlings; very few seedlings were culled.

Introduction

Root diseases of container-grown seedlings of western white pine (*Pinus monticola* Dougl.) periodically have damaged crops extensively, reducing the number of satisfactory seedlings produced and seedling quality (James 1985a; 1987a; 1990a; 1991a). The major fungal pathogens normally associated with such diseases include species of *Fusarium* and *Cylindrocarpon* (James 1985b; 1988a; 1990b).

In some cases, distinctive above-ground disease symptoms associated with extensive root colonization by these organisms are evident (James 1987a; 1989a; 1990a; 1991b; 2003b). All too often, however, no disease symptoms are discernable, even though root decay may be extensive (James 1988a; 1991c; 1991d; 2004a). In such cases, disease becomes evident only after seedlings are removed from containers; they may have high levels of root decay, requiring culling.

In most previous investigations, associated fungal organisms were determined at the end of the crop-growing cycle, when diseased seedlings were detected after lifting. Information on the temporal changes in fungal root colonization during a typical crop production cycle by different potentially pathogenic organisms has been lacking. This evaluation was recently conducted to provide such information, with the specific goal of determining changes in root colonization by *Fusarium* and *Cylindrocarpon* spp. during the crop production cycle.

Materials and Methods

A large container nursery in Idaho, which has traditionally produced many western white pine seedlings each year for reforestation, was selected. All seed used to produce seedlings was obtained from the same seed orchard, which produces improved seed developed for resistance to white pine blister rust (*Cronartium ribicola*). A sample of 100 seeds from bulk storage was analyzed for surface contamination by *Fusarium* and *Cylindrocarpon* spp. Seeds were placed aseptically on a selective agar medium for *Fusarium* and closely related fungal species (Komada 1975). Agar plates were incubated under diurnal cycles of cool fluorescent light at about 24 ˚C for 7–10 d. Selected emerging fungi were transferred to carnation leaf agar (Fisher and others 1982) and potato dextrose agar for identification according to the taxonomy of Nelson and others (1983) and Booth (1966). Percentages of seeds colonized by particular fungal species were determined.

Seedlings were grown in three production areas: two greenhouses (designated GH5 and GH7) and one shadehouse area (designated "Bay"). Seedlings were grown in two container sizes, 5s (120 cells block^{-1}) and 8s (91 cells block^{-1}) and sampled eight times at approximately monthly intervals, beginning about 6 wk after sowing. During each sampling period, five seedlings were randomly selected from each of the production areas and container sizes for laboratory analysis of fungal root colonization; this resulted in four separate samples (GH7–5s; GH7–8s; GH5–8s; Bay–8s; no seedlings were grown in 5s containers in GH5 or the shadehouse) during each sampling period. Selected seedlings were carefully extracted from containers, placed into individual plastic bags, transported to the laboratory, and analyzed immediately for fungal root colonization.

Seedling roots were washed thoroughly to remove adhering peat growing medium. Ten root pieces, each approximately 5 mm (0.2 in.), were randomly dissected from each seedling, surface-sterilized in 0.5-percent aqueous sodium hypochlorite (10-percent bleach solution), rinsed in sterile water, placed on the selective agar medium, and incubated as described above. Associated *Fusarium* and *Cylindrocarpon* spp. were identified and percentages of sampled root pieces colonized by particular fungal species were determined.

When seedlings were lifted from containers at the end of the production cycle, a total of 63 seedlings were collected for examination of their root systems (plugs) to determine extent of noticeable root decay. Seedling root plugs were placed into one of three categories based on the extent of root decay. Poor root systems exhibited extensive root decay with few roots remaining at the bottom of the plug. Moderate root systems had an intermediate level of root decay that may have compromised the root plug integrity; i.e., some of the growing media became dislodged when seedlings were extracted from containers. Good root systems exhibited very little or no noticeable root decay, and the root plug integrity was maintained upon seedling extraction. The percentage of seedlings culled due to poor root development (indicating decay and associated effects on root plug integrity) was determined from seedlings extracted from five randomly selected containers in each of the four sampled production areas.

Table 1. Contamination of western white pine seeds with *Fusarium* and other selected fungi.

Fungal species	Percent contamination[1]
Fusarium acuminatum	73
F. culmorum	20
F. proliferatum	5
F. equiseti	3
All *Fusarium*	98
Cylindrocarpon destructans	2
Botrytis cinerea	1

[1] Sample based on 100 seeds randomly selected from bulk storage before sowing.

Results

Nearly all sampled western white pine seeds were contaminated with at least one species of *Fusarium* (table 1). Four *Fusarium* species were detected on bulk seed samples. These included, in descending order of prevalence, *F. acuminatum* Ell. & Ev., *F. culmorum* (W.G. Smith) Sacc., *F. proliferatum* (Matsushima) Nirenberg, and *F. equiseti* (Corda) Sacc.

Extent of root colonization by *Fusarium* was initially higher in GH7 than in the two other production areas (table 2). In some cases, high levels of *Fusarium* colonization were detected early in the seedling production cycle, whereas in others levels of colonization generally increased over time. (Fluctuations from month to month were the result of the small sample sizes.) The highest overall *Fusarium* root colonization was detected about 30 wk after sowing (table 2). Eleven *Fusarium* species were detected on seedling roots (table 3). By far the most prevalent *Fusarium* species isolated from seedling roots was *F. proliferatum*. Seven

Table 2. Percent colonization of container western white pine seedling roots with *Fusarium* spp.

Sample time[1]	Production area[2]				
	GH 7–5s	GH 7–8s	GH 5–8s	Bay–8s	All samples
6	97	52	11	25	48
10	66	46	22	24	37
14	96	76	18	72	67
18	62	88	68	76	74
22	74	74	36	66	68
26	94	96	50	46	72
30	80	100	66	90	84
36	59	75	62	62	63
Averages	72	79	47	60	64

[1] Week after sowing.

[2] Each seedling production area designated with greenhouse number (or open shade house area–Bay) and the container sizes used in that area (5s=120 cells block^{-1}; 8s=91 cells block^{-1}).

Table 3. *Fusarium* species colonizing roots of container western white pine seedlings.

Fusarium species	Percent of samples[1]	Percent root colonization[2]
F. proliferatum	100	48.5
F. acuminatum	88	6.0
F. culmorum	75	3.9
F. avenaceum	50	3.2
F. oxysporum	50	1.2
F. sporotrichioides	25	0.9
F. scirpi	25	0.7
F. sambucinum	12	0.4
F. equiseti	50	0.4
F. tricinctum	12	0.3
F. heterosporum	12	0.1
All species	100	64.5

[1] Percent of the 8 sampling times throughout the growing season that particular *Fusarium* species were detected.

[2] Overall percent of sampled root pieces colonized by particular *Fusarium* species—total number of root pieces sampled=1,953.

were found only at extremely low levels; three others [*F. acuminatum*, *F. culmorum*, and *F. avenaceum* (Fr.) Sacc.] were isolated more frequently. *Fusarium* was isolated from an average of nearly two-thirds of the sampled root pieces throughout the sampling period (table 3).

The other assayed group of root-colonizing organisms was *Cylindrocarpon*. These fungi were detected at much lower levels than *Fusarium* spp. (table 4). *Cylindrocarpon* spp. were not detected until seedlings were 18 wk old in one production area (GH7) or 22 wk old in the other two areas. By the end of the production cycle, *Cylindrocarpon* spp. were detected on a little more than a third of the sampled roots (table 4). By far the most common *Cylindrocarpon* species isolated from roots was *C. destructans* (Zins.) Scholten. These pathogens probably get into the crop via contaminated seeds, containers, and debris within and adjacent to greenhouses (James and Dumroese 2007). They are not commonly found in the irrigation supply or the peat-based media. Some species, such as *F. proliferatum*, likely can be spread by air movements (James and others 1997).

Table 4. Percent colonization of container western white pine seedling roots with *Cylindrocarpon* spp.

Sample time[1]	Production area[2]				
	GH 7–5s	GH 7–8s	GH 5–8s	Bay–8s	All samples (mean)
6	0	0	0	0	0
10	0	0	0	0	0
14	0	0	0	0	0
18	40	4	0	0	14
22	70	8	42	22	36
26	12	2	44	34	23
30	38	0	20	20	20
36	61	31	26	17	35
Averages	37.5	10	19	13.5	20

[1] Week after sowing.

[2] Each seedling production area designated with greenhouse number (or open shade house area–Bay) and the container sizes used in that area (5s=120 cells block^{-1}; 8s=91 cells block^{-1}).

[3] *Cylindrocarpon* isolates comprised 99-percent *C. destructans* and 1-percent *C. gracile*.

Table 5. Percent of sampled seedlings within root plug condition categories and percent culls of container western white pine seedlings at the time of lifting (36 wk after sowing).

Production area	Root plug condition[1]			Percent seedling culls[2]
	Poor	Moderate	Good	
GH7–5s	26	21	53	2.0
GH7–8s	0	8	92	2.0
GH5–8s	0	15	85	2.5
Bay–8s	21	21	58	7.3
Averages	14.3	17.5	68.2	3.5

[1] Visible condition of plugs at the time of lifting, based on extent of noticeable root decay (poor=extensive root decay and/or few roots remaining at the bottom of the plug; moderate=moderate root decay with compromised root plug integrity; good=little or no root decay evident; root plug integrity maintained). Number of seedlings sampled: GH7–5s =19; GH7–8s=12; GH5–8s=13; Bay–8s=19; total=63.

[2] Five randomly selected styrofoam blocks with seedlings sampled per production area at the time of lifting. Number of cells sampled: GH7–5s=600; GH7–8s=455; GH5–8s=728; Bay–8s=455; total=2,238.

Percent of seedlings culled due to poor root condition was quite low (table 5). More than two-thirds of the examined root systems at the time of lifting were considered to be in good condition, based primarily on the extent of noticeable root decay (table 5). In some cases (GH7–8s; GH5–8s), no seedlings examined had poor root systems.

Discussion

Excessive root decay of container western white pine seedlings, resulting in high cull levels and poor outplanting performance, is normally ascribed to high levels of root colonization by *Cylindrocarpon* spp., especially *C. destructans* (James 1988a; James and others 1994; James 2003a, 2004a). These fungi are routinely isolated from seedling roots exhibiting decay symptoms (James 1988b; James and others 1994; James 1995, 2000). High seedling losses in nurseries have often been associated with excessive moisture being maintained for prolonged periods within root plugs. Fortunately, *Cylindrocarpon* levels on colonized roots tend to decrease over time following outplanting onto forest sites and usually do not adversely affect seedling survival (Dumroese and others 2000).

Although *Cylindrocarpon* has been associated with important conifer seedling diseases in nurseries (Evans 1967; Bloomberg and Sutherland 1971; James 1988a; Unestam and Beyer-Ericson 1991; Beyer-Ericson and others 1991; James 2004b), the aggressiveness of this species has been questioned, especially when seedlings are grown under nonstressful conditions (Dahm and Strzelcayk 1987a, b). In fact, many western white pine seedlings with extensive root decay attributed to *Cylindrocarpon* exhibit no disease symptoms during the production cycle; they are detected only once seedlings have been removed from their containers (James 1988a; James and others 1994).

In this evaluation, *Cylindrocarpon* spp., primarily *C. destructans*, were isolated at fairly low levels, especially when compared to root colonization by *Fusarium* spp. *Cylindrocarpon* was not detected early in the crop production cycle, and relatively high colonization frequency was found only in one production area (GH7) at the time of lifting.

On the other hand, *Fusarium* root colonization was generally much higher during all sampling periods. Although a wide range of species were isolated from seedling roots, *F. proliferatum* was by far the most common. This species has been implicated often in container seedling root diseases (James and others 1995; James and Dumroese 2006); some isolates can be highly virulent on young conifer seedlings, at least under controlled greenhouse growing conditions or during *in vitro* laboratory experiments (James and others 1997). Although previous evaluations indicated that *F. proliferatum* increases root colonization as the seedling crop ages (James and Gilligan 1990; James 1991a, 1991b), relatively high levels of root colonization by this fungus were found on very young seedlings in this evaluation.

Fusarium and *Cylindrocarpon* inocula have often been detected on sown white pine seeds (James 1987b; 1987c; 1988a; 1989b), on containers used to grow previous seedling crops (Dumroese and others 2002), and on various types of organic matter within and adjacent to greenhouses (James 2003a; James and Dumroese 2006). In this evaluation, *Cylindrocarpon* was detected on only 2 percent of the sampled seeds. Although *Fusarium* spp. were detected at high levels on seeds, *F. proliferatum*, the species with the highest disease potential (James and others 1995, 1997), was found on only 5 percent. Therefore, it appears that contaminated seeds were not an important source of potentially pathogenic *Fusarium* or *Cylindrocarpon* spp.

Styrofoam containers used to produce seedlings were not sampled in this evaluation. However, growers use standard hot water sterilization to clean containers that have been used to produce previous seedling crops. These treatments have usually been quite effective in eliminating inoculum of potentially pathogenic fungi (Dumroese and others 2002). Therefore, it is unlikely that high levels of either *Cylindrocarpon* or *Fusarium* were introduced into the white pine seedling crop by contaminated containers.

Organic debris within or surrounding seedling production greenhouses or shade houses may have contributed *Cylindrocarpon* and *Fusarium* inoculum. Weeds can also harbor these fungi. Neither organic debris nor weeds were assayed for potential pathogens, however, so the extent of these two sources as a source of *Cylindrocarpon* or *Fusarium* inoculum is unknown.

Root diseases caused by *Cylindrocarpon*, *Fusarium* spp., or both will continue to be of concern to container seedling growers. Both groups of fungi can cause devastating losses when virulent fungal isolates and conducive environmental conditions are present. Although losses during the current evaluation were very low, continued low disease levels cannot be guaranteed for the future. Careful vigilance by growers will be necessary to make sure seedling crops are not stressed to the point where these potential pathogens can cause important losses.

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Ten-Year Response of Western Larch and Douglas-fir Seedlings to Mulch Mats, Sulfometuron, and Shade in Northeast Oregon

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Abstract

This trial investigated the effectiveness of small-scale vegetation management treatments on seedling survival and growth. Treatments included a black mulch mat, a spot application of sulfometuron, and control; in each of these treatments, half the seedlings were shaded. Costs of the treatments were evaluated. Vegetation management and shade improved seedling survival after 4 and 10 yr. After 10 yr, individual seedling and per-area volume growth in the weed control treatments outperformed the control; in some cases, they were diverging. Lowest cost per established seedling was obtained by using sulfometuron without shade.

Introduction

Vegetative competition from grasses, sedges, forbs, shrubs, and hardwood trees can lower conifer seedling survival and growth (Stewart and others 1984; Walstad and Kuch 1987). In reviewing 60 of the longest term studies, Wagner and others (2006) stated that reducing competition with vegetation management substantially increased tree growth for many species and sites worldwide. Managing competing vegetation is essential to plantation establishment, especially in areas of the Western United States where summers are typically hot and dry and humidity and soil moisture are low during the growing season. Reducing competition for soil moisture is critical to seedling performance, particularly during the early years of seedling establishment (Newton 1973).

Although effects of vegetation management on seedling performance of Douglas-fir [*Pseudotsuga menziesii* var. *menziesii* (Mirb.) Franco] have been studied extensively in western and southwestern Oregon (Hobbs and others 1992), the Rocky Mountain type [*Pseudotsuga menziesii* var. *glauca* (Mirb.) Franco] and western larch [*Larix occidentalis* (Nutt.)] in eastern Oregon have received little attention. Most of the few studies conducted in the inland Northwest have demonstrated that reducing competing vegetation enhances establishment of Douglas-fir and western larch. Boyd (1986), summarizing results of 24 site-preparation trials in the northern Rocky Mountains, reported that vegetation management with herbicides improved the Plantation Growth Index (PGI) up to 5-fold after 6 yr for Douglas-fir and up to 3-fold after 3 yr for western larch, compared with the control treatment [PGI=(survival)(stem volume)]. Dimock and others (1983) reported that stem volume yield of hexazinone-treated 2-0 bare-root Douglas-fir seedlings near Entiat River, WA, increased 650 percent over untreated checks after 6 yr. Graham and others (1995) studied western larch germination in the Northern Rocky Mountains on burned-over ground, natural mineral soil, rotten wood, and duff. They found significant short-term growth improvements of 5–11 percent if organic materials were enriched and competing vegetation was controlled. In a summary of western larch ecology and silviculture in northern Idaho and western Montana, Schmidt and others (1976) stated that naturally regenerated larch grows twice as fast on mineral seedbeds where most of the competing vegetation has been removed than it does on heavily vegetated forest floor, at least for the first 15 yr.

Shading can substantially improve survival of Douglas-fir seedlings on droughty sites in southwestern Oregon (Minore 1971; Hobbs 1982; Helgerson 1990). Survival appeared to be better when shade was placed on the south side of seedlings than when it was on the east side (Helgerson 1990). Strothman (1972) found, however, that shade may not be necessary for Douglas-fir seedling survival on drier, south-facing slopes in the coast range of northern California. Evidence of benefits to Douglas-fir seedling growth from using shadecards has been lacking (Helgerson and others 1992).

Woodland owners and industrial forest land managers in eastern Oregon are planting more Douglas-fir and western larch for economic and forest health reasons (Knight 2007, personal communication). Few, if any, studies of these species on eastside forest sites have evaluated vegetation management options, shading effects on seedling performance, or their associated costs and benefits. The objective of this trial was to examine the effectiveness of small-scale vegetation management treatments and shade on the survival, growth, and costs of plantation-grown western larch and Douglas-fir seedlings.

Methods

Study Areas. The study areas were on the Eastern Oregon University Rebarrow Research Forest and the Oregon State University Obertueffer Research and Education Forest (Obie) near La Grande, OR (45º3´ N, 118º09´ W). On both sites, annual average precipitation is 64–76 cm (25–30 in), deposited largely as snow (Oregon Climate Service 2008). Warm, dry summers are common.

Rebarrow. On Rebarrow, plots were located at 1,616 m (5,300 ft) elevation, facing west on gentle slopes (<5 percent). A few scattered grand fir [*Abies grandis* (Dougl.) Lindl.], Douglas-fir, and western larch (<10 per acre) were in the overstory. The understory was fully occupied by orchard grass [*Dactylis glomerata* (L.)], elk sedge [*Carex geyeri* (Boott)], and pine grass [*Calamagrostis rubescens* (Buckley)], as well as scattered clumps of snowberry [*Symphoricarpos albus* (L.) Blake], willow [*Salix sp* (L.)], grouse huckleberry [*Vaccinium sp* (L.)], oceanspray [*Holodiscus discolor* (Pursh.) Maxim.], and mallow ninebark [*Physocarpus malvaceus* (Greene) Ktze.].

Rebarrow is on the cool end of a warm, dry mixed-conifer type (Emmingham and others 2005). The soil is a moderately deep, well-drained, very stony Kamela silt loam with a site index of 70 for Douglas-fir on a 100-yr basis (Dyksterhuis and High 1985). A few years before planting, the area had been salvage-logged following an outbreak of western spruce budworm [*Choristoneura occidentalis* (Freeman)]. Light amounts of slash covered the site.

Obie. Plots on Obie were located on a warm, dry mixed-conifer type (Emmingham and others 2005) with north to northwest exposures and slopes of <5 percent at an elevation of 1,226 m (4,020 ft). The treatment area was an old pasture, fully occupied and dominated by orchard grass. The soil is a deep, well-drained Lookingglass silt loam (Dyksterhuis and High 1985). The Douglas-fir site index is 95 on a 100-yr basis (Cochran 1979).

Treatments. For each species, 20 5-cm³ (0.31-in³) containerized seedlings were planted on 3.7 m (12 ft) × 3.7 m (12 ft) spacing in 6 plots in each of three treatments: 0.8-m² (9-ft²) black plastic mulch mat, 0.8-m² (9-ft²) spot application of sulfometuron (Oust), and no treatment (control) at each of two sites. A buffer of 7.3 m (24 ft) was left between each plot.

The three treatments were blocked by species, with each treatment randomly located and adjacent to the other treatments. Treatment areas measured 11 m (36 ft) wide × 86 m (282 ft) long. Planting was completed on May 1, 1997, by a contract planting crew. On every other plot in each treatment, seedlings were shaded on the south-southwest side of the seedling with a 20-cm (8-in) × 31-cm (12-in) black mesh Tree Shade card (Terra Tech, Inc., Eugene, OR). According to the manufacturer, they provide about 80 percent shade to the seedling. Black PAK Ground Cover mats (Terra Tech, Inc., Eugene, OR) were purchased in bulk, cut to size, placed over planted seedlings, and secured to the ground by five landscape staples. Sulfometuron was applied over the top of dormant seedlings with a backpack sprayer at a rate of 292 mL ai ha^{-1} (4 oz ai ac^{-1}) with a total spray volume of 183 L ha^{-1} (20 gal ac^{-1}). Installations and applications occurred before seedling budbreak in spring 1997.

Data Collection. Data collection included survival and growth. For Rebarrow, survival was monitored after the growing season in the first, second, third and fourth year. Survival was recorded as the number of live trees at the end of each growing season. Growth information was collected at the end of the third and fourth year. The Rebarrow site was abandoned in subsequent years because of poor survival in all treatments. At Obie, survival was monitored at the end of the growing season in the 1st, 2nd, 3rd, 4th, 5th, 8th and 10th yr. Growth was measured in the 3rd, 4th, 5th, 8th and 10th yr.

Total seedling height and diameter were recorded. Stem volume per seedling was calculated with the formula for a cone [$V = \pi D^2 H/12$, where D=diameter and H=height]. Volume per area calculations assumed 741 trees ha^{-1} (300 trees ac^{-1}) and used treatment means for survival and growth at the end of 10 yr at Obie. Data were recorded before budbreak on eight seedlings per plot in 1997; because of poor survival in some of the plots, however, growth was recorded for all live trees for determining means. Diameters were taken within 2.5 cm (1 in) of the soil surface; heights were measured from the top of the terminal bud. Mean seedling size at the time of planting was 3.1 mm (0.12 in) basal diameter and 25.4 cm (10 in) height for western larch and 2.1 mm (0.08 in) basal diameter and 13.1 cm (5.2 in) height for Douglas-fir (n=144).

Data Analysis. A statistical analysis was not performed because of several confounding factors. First, treatments were not laid out in a completely randomized design. Second, a stand of trees at Obie cast some late afternoon shade on two plots in the Douglas-fir mat treatment. Finally, although treatments within a block were relatively close to each other, there may be soil differences between treatment areas that are not accounted for. While the effect of this confounding is unknown and inferences from the data are limited, this trial has value as a case study that can contribute to a limited knowledge base.

Four-Year Results

Rebarrow. *Survival.* The mat and sulfometuron treatments improved survival of western larch seedlings about two-fold compared with the control at 4 yr (table 1). Mats improved Douglas-fir seedling survival by 56 percent, but spot applications of herbicide had no effect on survival compared to control. Shade enhanced survival 2.2-fold in western larch and 2.6-fold in Douglas-fir.

Growth. Herbicide and mats increased volume growth of western larch seedlings by 55 percent and 48 percent, respectively, compared with no treatment. Douglas-fir seedling growth was enhanced with vegetation management even more. Shade did not appear to improve larch or Douglas-fir seedling growth.

Obie. *Survival.* Seedling survival across all treatments at Obie was higher than at Rebarrow (table 1), with larch seedling survival increasing almost 4-fold in the mat and herbicide treatments, compared with the control. Control of competing vegetation was not as effective for Douglas-fir survival, where mats and herbicide increased survival by 44 percent and 220 percent, respectively, in relation to control. Shade improved survival 38 percent and 61 percent for larch and Douglas-fir, respectively, compared to no shade.

Growth. Reducing competing vegetation increased tree volume growth for both western larch and Douglas-fir relative to controls (table 1). Spot treatment with sulfometuron increased larch tree size almost 5-fold, and mats provided an 8-fold increase. Douglas-fir showed much smaller growth improvements with weed control. Although western larch seedlings showed no apparent growth benefit with shade, shaded Douglas-fir seedlings were 2.7 times larger than unshaded.

Ten-Year Results

Rebarrow. Because of poor survival in all treatments, the Rebarrow site was abandoned after the fourth year.

Obie. *Survival***.** Survival of western larch seedlings was 3–4 times greater when competition was controlled than in the control treatment (figure 1). Except for mats without shade, weed control substantially improved Douglas-fir seedling survival through year 10 as well, with the shaded mat and spot herbicide treatments showing survival rates of 63 percent and 78 percent, respectively, compared with 40 percent in the shaded control (figure 1). Shade appeared to have a greater effect on Douglas-fir seedling survival than

Table 1. Treatment comparisons of survival, height, basal diameter, and individual tree volume of Douglas-fir and western larch seedlings at Rebarrow and Obie in year 4.

	Rebarrow					Obie				
	Control	Mat	Sulfometuron	Shade	No shade	Control	Mat	Sulfometuron	Shade	No shade
Western larch										
Survival (%)	16.0	33.0	28.3	29.0	13.0	19.0	75.0	76.0	66.0	48.0
Height (cm)	50.5	57.1	55.1	55.0	55.6	61.7	101.4	96.3	91.5	92.7
Basal diameter (mm)	8.3	9.5	9.8	9.0	9.8	8.5	18.7	15.1	15.8	15.0
Volume (cm^3)	9.1	13.5	14.1	11.7	14.0	11.7	92.8	57.5	59.8	54.6
Douglas-fir										
Survival (%)	23.0	36.0	18.0	37.0	14.0	32.0	46.0	71	61.0	38.0
Height	26.5	35.1	40.6	37.7	35.1	37.9	42.0	37.8	46.1	30.6
Basal diameter	5.9	8.6	8.8	8.3	8.3	7.9	9.1	8.4	9.7	7.2

on western larch, increasing survival by 100 percent in the control treatment and almost tripling survival when shade was used with mats. Shade benefits were less dramatic for herbicide-treated seedlings (data not shown).

Growth. Individual unshaded western larch seedlings in the herbicide or mat treatment grew 5 to 6 times larger than seedlings in the control; however, the benefits of weed control were somewhat less for shaded seedlings (figure 2). Individual mean tree volume of Douglas-fir seedlings in the mat treatment with shade was twice as large as that in seedlings in the shaded control or herbicide spot spray treatments (figure 2). Herbicide spot treatment without shade produced a 70-percent increase in seedling size compared to unshaded seedlings in the mat and control treatments. Shade more than doubled the mean individual Douglas-fir tree volume compared with seedlings without shade; however, there was no difference between shaded and unshaded treatments for western larch (figure 3).

Area volume yields of western larch were 15 times greater in the herbicide treatment than in the control (figure 4). The mat treatment response was even higher, yielding 21 times the yield of the control. Seedlings grown with mats provided about 40 percent more volume per area than those treated with herbicides. Area volume yields of Douglas-fir in the shaded mat treatment grew more than twice as much as in the shaded herbicide treatment and nine times as much as in the unshaded mat and control treatments (figure 4). Douglas-fir seedlings in the shaded herbicide treatment grew 48 percent more volume per area than shaded controls.

Cost analysis. In both species, cost was lowest in the unshaded herbicide treatment, followed closely by the shaded herbicide treatment (table 2). Although shading generally improved seedling survival, this advantage was not enough to offset the added cost of shade cards, except in the control and mat treatments for Douglas-fir. (There was only a $0.02/seeding benefit for shaded trees in the larch mat treatment). Mats were a lower cost alternative than no treatment for larch because of the large difference in survival rates between the treatments.

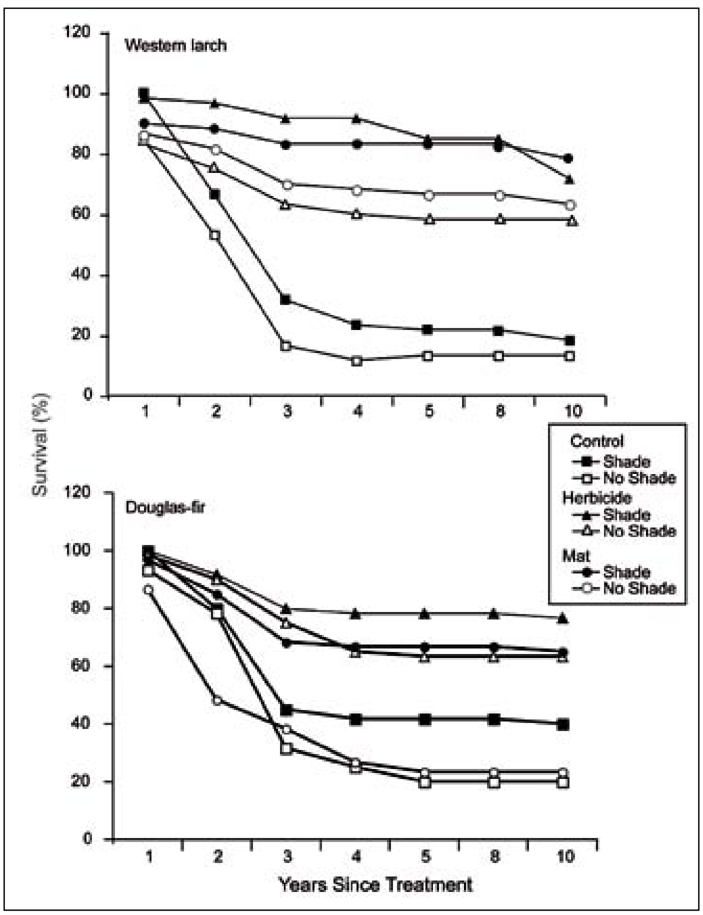

Figure 1. Mean survival by treatment for western larch and Douglas-fir 10 yr after planting.

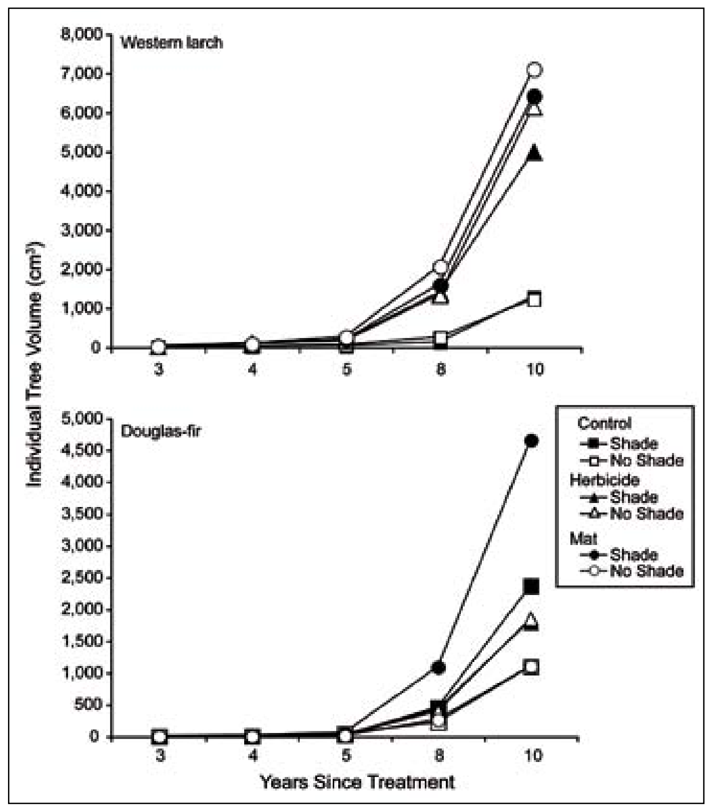

Figure 2. Mean individual tree growth at Obie by treatment for western larch and Douglas-fir through the first 10 yr after planting.

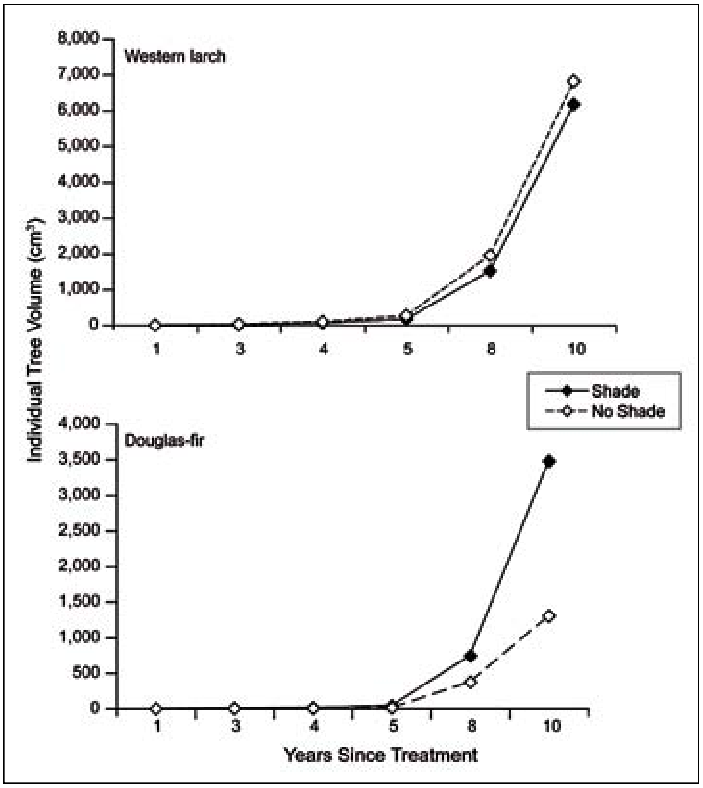

Figure 3. Mean individual tree volume at Obie for western larch and Douglas-fir, with and without shade, through the first 10 yr after planting.

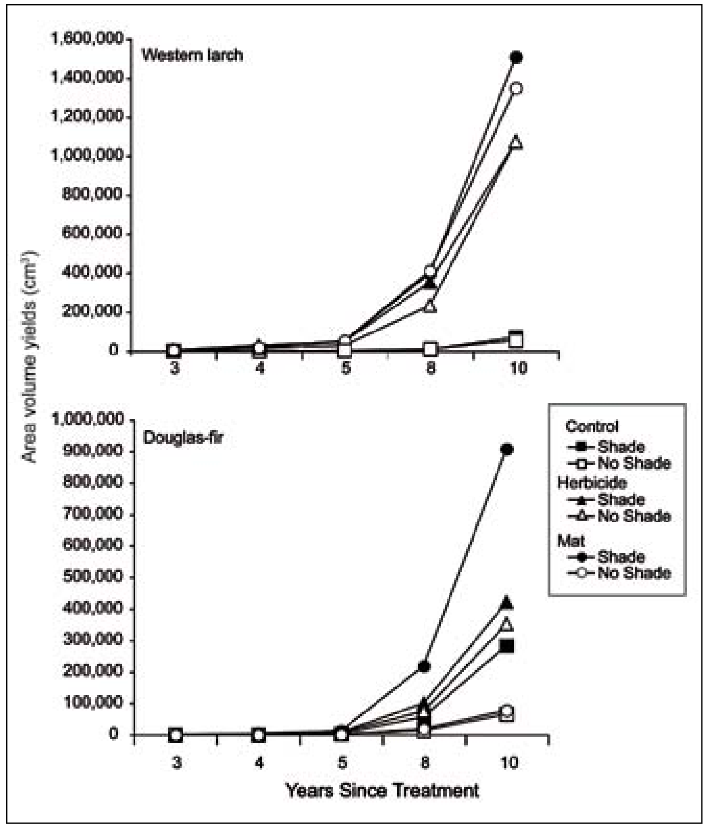

Figure 4. Mean per acre volume growth by treatment at Obie for western larch and Douglas-fir through the first 10 yr after planting.

Table 2. Year 10 established seedling cost by treatment at Obie.

	Control		Herb		Mats	
	Shade	No shade	Shade	No shade	Shade	No shade
Cost per acre ($)[1]	291	177	339	225	624	510
Western larch						
Established seedlings per acre[2]	55	45	215	175	235	190
Cost per seedling ($)	5.29	3.93	1.58	1.29	2.66	2.68
Douglas-fir						
Established seedlings per acre	120	60	230	190	195	70

[1] Cost assumptions (in 1997 dollars):
- 300 trees planted ac^{-1}.
- Douglas-fir and western larch seedlings: $240 per 1000.
- Planting: $0.35 $seedling^{-1}$.
- Sulfometuron herbicide: $3.25 ac^{-1}.
- Herbicide application: $45.00 ac^{-1}.
- Mats: bulk mats $186 ac^{-1}, application $75.00 ac^{-1}, staples $12.00 ac^{-1}, cutting mats $60.00 ac^{-1}.
- Tree shades: shade card $45.00 ac^{-1}, wickets $30.00 ac^{-1}, installation $37.50 ac^{-1}.

[2] Established seedlings per acre at year 10 = (300)(percent survival).

Discussion

The results presented here are consistent with other spot-treatment vegetation control studies in the region (Barber 1984; Oester and others 1995). Barber (1984) tested 1-m² (11-ft²) site-preparation spot treatments with atrazine and hand scalps of 0.15 m² (1.6 ft²) on a grassy site near Cle Elum, WA. First year 2-0 Douglas-fir survival was improved about 5-fold and predawn moisture stress of seedlings dropped by 4.5-fold after atrazine treatment, compared with the control. Oester and others (1995) found that 2-0 ponderosa pine trees faced with grass competition survived 250 percent better and were 350 percent larger than control trees 5 yr after hexazinone treatment. This study found the same trends: after 10 yr, spot herbicide applications doubled survival of Douglas-fir seedlings, and small mulch mats doubled Douglas-fir tree growth. The sulfometuron spot spray or mat improved western larch survival 3–4-fold and tree growth 6–8-fold.

The long-term seedling survival and growth improvements with sulfometuron for western larch on the Obie site suggest that this low-cost, one time treatment could be an effective choice for woodland owners looking for reasonable boosts in performance for a relatively small investment. Mats could be an alternative for woodland owners who want comparable performance, but would rather not use herbicides; however, the cost will be higher (table 2). For the most part, the same can be said for Douglas-fir; however, there are two differences. First, if black mulch mats are used to establish Douglas-fir on open sites, a shade card is essential to prevent high seedling mortality, which will increase cost. Second, although the sulfometuron treatment controlled weeds enough to improve Douglas-fir survival, it did not benefit growth after 10 yr at Obie. The retarded growth of Douglas-fir with sulfometuron is not uncommon and could have been caused by the higher application rate [293 ml ai ha^{-1} (4 oz a.i. ac^{-1})] used in this trial (Justice 2007, personal communication). Those owners who want to use an herbicide treatment and prevent growth setbacks should consider using an alternative to sulfometuron or consulting a herbicide specialist for recommendations.

If mulch mats are preferred and cost is not an issue, a larger mat may be used to improve growth response. In a 5-yr study in the coast range of northern California, comparing large and small mulch mats, a small scalp and control, McDonald and others (1994) found that mean diameter of Douglas-fir seedlings grown with large mats [9.3 m^2 (100 ft^2)] was significantly greater than that of the control and scalp treatments.

Increasing the area of a competition-free zone around seedlings has been shown to improve conifer growth in a number of species and locations (Jaramillo 1988; Mason and Kilongo 1999; Rose and others 2006; Wagner and Robinson 2006), with site productivity and species influencing the optimal area of weed control around seedlings (Richardson and others 1996; Wagner and Robinson 2006). After 10 years at Obie, the two small area weed control treatments apparently gave seedlings enough additional site resources to start them on a growth trajectory greater than that of the control and diverging from the latter with time. Rose and others (2006) found that Douglas-fir growth response on a coastal site in Oregon to a 1.49-m^2 (15.5-ft^2) spot application of herbicide was about 65 percent of the tree growth potentially obtainable with total vegetation control, after 12 yr. Based on the trends presented here, potentially greater growth improvements could be achieved with more intensive vegetation control.

On the open sites in this study, shaded seedlings in general showed greater survival than unshaded seedlings, which is consistent with other studies (Lewis and others 1978; Hobbs 1982; Helgerson 1990; Helgerson and others 1992). Shade cards lower surface soil temperature and reduce soil surface evaporation and soil water loss, increasing soil moisture available for seedling use (Flint and Childs 1987). This trial indicates that shade may improve growth of Douglas-fir seedlings; however, the lack of statistical analysis limits inferences, and more rigorous study is needed. Shade did not improve growth of western larch, possibly due in part to its high intolerance to shade (Schmidt and Shearer 1990). The high mortality observed with unshaded Douglas-fir seedlings in the mat treatment likely resulted from elevated temperatures around the seedling caused by the high heat absorption properties of black mulch mats. Other mortality causes, such as animal damage from voles, were not observed to differ between shaded and unshaded seedlings. Western larch did not show similar survival trends with mats.

Other stock types or sites may show different trends from those in this study. Hobbs (1982) found that shade cards improved survival of Douglas-fir bareroot seedlings on south-facing slopes in southwest Oregon. He suggested, however, that stocktype selection may be as important as shadecards on those soils and that any gains in survival or growth from shadecards may depend strongly on site characteristics.

The lower survival of both western larch and Douglas-fir in the first 4 yr at Rebarrow was probably due to harsher site conditions at Rebarrow. The soils at Rebarrow are shallower and have higher rock content, less ash, and a lower soil–water-holding capacity than those at Obie (Dyksterhuis and High 1985). The aspect at Obie is more northerly, and Rebarrow supports a low-growing shrub community, in addition to grasses, that does not occur at Obie. Shrubs remove moisture at lower depths in the soil profile, effectively reducing available soil moisture for seedlings and increasing competition (Newton 1973). Light browsing by wild ungulates was observed at Rebarrow but not Obie. Finally, although precipitation was not monitored on site, precipitation amounts in LaGrande, OR, during the study averaged 10 percent lower than the 1971–2000 annual average of 444.5 mm (17.5 in) (Oregon Climate Service 2008). Three of the first 4 yr and 7 of the 10 yr of the study were below average in annual precipitation. The combined effect of these factors was likely responsible for the higher mortality on Rebarrow in spite of weed control efforts. Higher survival might have been achieved at Rebarrow by applying a higher level of competition control, planting well-balanced seedlings with large root systems, and protecting seedlings from animal damage. Site differences can have big effects on the level of response to and success of vegetation management treatments. The difference in seedling performance between these two sites when similar vegetation management treatments were applied is a good lesson that a "one size fits all" approach should be avoided.

Cost analysis indicates that shade cards are justified economically only for Douglas-fir seedlings planted with no vegetation management or when used in conjunction with mats. Less expensive sources of shade would improve the cost benefits of shade in the other options.

Although the no-treatment option was initially less expensive than the herbicide spot spray, survival fell short by up to 198 seedlings ha^{-1} (80 ac^{-1}), and cost per established seedling was more. Additional dollars would be needed for interplanting and weed control to bring stocking up, causing an even higher per-unit cost to meet management goals, including, in this case, achieving Oregon's Forest Practices Act minimum requirement of 125 trees ac^{-1}. Not only does the "cheap" way increase the real total cost, but also time on the production cycle is lost and the investment must be carried longer—and time is money (Talbert 2008).

Summary

Small, tree-centered spot vegetation management treatments of sulfometuron or plastic mulch mats have the potential to improve survival and growth of Douglas-fir and western larch seedlings on similar sites in northeast Oregon. Western larch appears to perform particularly well through the first 10 yr with small, one-time reductions in competition. More intensive weed control may show better responses. Shading seedlings generally improved survival; however, the added cost of shade cards was not financially feasible except where Douglas-fir was planted without weed control or when black plastic mulch mats are used. Less expensive shade alternatives may prove more cost effective. More research is needed to gain a better understanding of these relationships.

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Root Dip Treatments Affect Fungal Growth in vitro and Survival of Loblolly Pine (Pinus taeda)

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Abstract

Hydrogels and clay slurries are the materials most commonly applied to roots of pines in the Southern United States. Most nursery managers believe such applications offer a form of "insurance" against excessive exposure during planting. The objective of this study was to examine the ability of root dip treatments to (1) support fungal growth and (2) protect roots from injury during exposure for 1, 2, or 4 h. Four treatments were tested: kaolin clay, two grades of polyacrylamide hydrogels, and a cornstarch-based hydrogel. In petri dish tests, kaolin clay was the only treatment that inhibited the growth of three soil-borne fungi (*Pythium*, *Fusarium*, *Rhizoctonia*). When applied to roots, however, the clay slurry did not effectively prevent permanent root damage during exposure and subsequent mortality. Gel treatment provided some protection when roots were exposed to air for 2 or 4 h. If a gel treatment reduces the need for replanting only 1 ha in 3,333, the benefit/cost ratio might equal 2 (assuming a cost of \$500 ha^{-1} for replanting and a gel treatment cost of \$250 per 3.3 million seedlings).

Introduction

During the 19th century, roots were often kept moist at the nursery during counting and sorting to improve the chance of seedling survival (Hodges 1883). The practice of "puddling" has been used for more than a century; this involves dipping roots into a mixture of clay and water (the consistency of paint) either at the nursery (Goff 1897) or at the planting site (Hodges 1883; Pinchot 1907). It is interesting to note what Toumey (1916) said about freshly lifted stock: "Puddling is not necessary and usually does more harm than good." We know that washing roots to remove soil can reduce seedling quality (Carey and others 2001), which might explain why Toumey believed puddling harmed seedling quality. In some cases, washing roots was recommended in cases where puddling resulted in problems with aeration due to mud adhering to roots (Goff 1897). Toumey did suggest, however, that roots be thoroughly puddled if roots became "over-dry" during storage. Some questioned this claim, so later he changed the recommendation to applying water but not puddling (Toumey and Korstian 1949). Even today, recommendations vary, depending on whom you ask.

Several materials have been added to roots before packing seedlings. Sphagnum moss was preferred during the 19th and the first half of the 20th century; as moss became harder to acquire, alternative treatments were investigated (Davey 1964; Fisher 1974). Slocum and Maki (1956; 1959) reported benefits of treating roots with clay when seedlings were exposed to an hour or two of drying. In 1960, Weyerhaeuser asked that their seedlings be treated with clay at the nursery (Bland 1964), and this practice was quickly adopted by the North Carolina Forest Service Nursery at Goldsboro, NC. Soon after, other researchers began to report on tests using clay slurries (Dierauf and Marler 1967; 1971), and the practice spread. Some preferred clay dipping to moss, believing it made it unnecessary to have water in planting buckets because clay "protects seedling roots both before and after planting" (Hamner and Broerman 1967).

A few years later, sodium alginate became popular as a gel treatment in Germany and was subsequently tested in other countries (Miller and Reines 1974; Dierauf and Garner 1975; Bacon and others 1979). When roots were treated with sodium alginate and then exposed in a greenhouse for up to 5 d, seedling survival and the relative water content of needles were improved (Miller and Reines 1974). During the 1980s, nursery managers began operational use of polyacrylamide gels. In some cases, use of gels increases survival compared with root treatment with a clay dip (Venator and Brissette 1983). Polyacrylamide gels likely are preferred over clay because they usually cost less, require less storage space, and are less messy (Bland 1964). A nursery that produces 25 million seedlings may only need a pallet of product, while clay might require the delivery of 23 tonnes (25 tons) (Pryor 1988). Most managers agree with Alm and Stanton (1993), who believe that polymer gels “offer a form of insurance against survival loss resulting from seedlings being exposed to drying during the planting process.”

Despite this “insurance” aspect, there are no economic studies to support the use of either gels or clays in the production of loblolly pine (*Pinus taeda* L.). Therefore, these trials were initiated to examine the effects of three root dip treatments on their ability to (1) support fungal growth and (2) protect roots from injury during exposure.

Materials and Methods

Study I: Fungal Growth. This study was designed to address concerns that root treatments may support the growth of soil-borne fungi. In some cases, this might be detrimental to seedling survival. Treatments included kaolin clay, two grades of polyacrylamide hydrogels [PAM gels A and B (Soil Moist®, JRM Chemicals, Cleveland, OH)] and a cornstarch-based hydrogel, CSB gel (Zeba®, Absorbent Technologies, Beaverton, OR). Samples of the kaolin clay and PAM gels were obtained from the nursery; the CSB Gel was provided by the manufacturer. The particle size for each material was determined by passing the material through 250-µ and 500-µ sieves. The particle size and rate of material used for each treatment are provided in table 1. Companies offer different gel formulations based on particle size (Venator and Brissette 1983). Particle size can affect physical properties such as water-holding capacity and ability to go into suspension. The fungi used were pathogenic isolates of *Pythium* sp., *Fusarium* sp. and *Rhizoctonia* sp.

A 3-mm (0.12-in) plug of the fungus was placed on the center of a water-agar petri plate [85 mm diameter (3.3-in)] that had been augmented with either clay, PAM gel “A” or “B”, or CSB gel at a rate comparable to nursery use. Water agar is a basic medium made with distilled water that supports minimal fungal growth. Control plates held water agar without any gel or clay amendments. Each treatment was replicated 12 times. The radial growth of each fungus was recorded daily. Differences in fungal growth on the various amended media demonstrate the ability of the gel or clay to support fungal growth, relative to that of unamended media.

Study II: Seedling Survival Following Exposure. Each treatment (table 1) was mixed in a separate bucket with 7.5 L (2 gal) of tap water. The clay had to be stirred continuously during treatment, since the clay never dissolved. Both PAM gels dissolved with less than 1 min of stirring; gel “A” dissolved faster than gel “B”. The CSB gel, however, was very difficult to mix. When it was placed in the water, it immediately clumped and required considerable stirring and agitation to break up the clumps. Once this was done, it was similar in appearance to the PAM gels.

The amount of gel sprayed operationally on roots of machine-lifted loblolly pine is approximately 3.6 g (0.13 oz) per seedling. Dipping roots of 20 seedlings 5 times removed about 72 g (2.5 oz) of gel solution, or about 3.6 g (0.13 oz) of gel per seedling. All root gel or clay treatments were hand-dipped five times before exposure.

Seedlings were treated with one of four root treatments (table 1); the roots of control seedlings were dipped into water. The seedlings (20 per experimental unit) were laid on an expanded metal bench in the greenhouse for 0, 1, 2, or 4 h. Greenhouse temperatures during exposure ranged from 28 to 37 °C (82.4 to 98.6 °F); relative humidity ranged from 16 to 38 percent. The average solar radiation measured within the greenhouse was 22,700 lumen m^{-2} (2,100 lux).

After exposure, seedlings were transplanted at the Southern Forest Nursery Cooperative’s seedling testing facility. This facility consists of six pits [23 m (75 ft) × 23 m (75 ft) × 1 m (3 ft)] containing 100 percent sand. Twenty treatments (5 root × 4 exposure treatments) were replicated 12 times in a randomized complete block design with 5 seedlings per experimental unit. The sand in the pits was irrigated for 4 h before planting. In order to obtain a separation among treatments, irrigation was withheld after

Table 1. Percentage of material passing through a 500-µ and a 250-µ sieve and rate of material used expressed as total mass of material per liter (L) of water.

Particle size	Material (%)			
	Clay	PAM gel “A”	PAM gel “B”	CSB gel
>500µ	3.4	60.0	3.0	0
500–250µ	16.2	22.8	54.2	34
<250µ	80.4	17.2	42.8	66
Mass (g)	300	2.2	3.3	1.8

transplanting. Rainfall for the test period from February 7 to May 7 totaled 15.9 cm (6.3 in): 5.0 (2 in), 7.1 (2.8 in), 3.8 (1.5 in), and 0.0 cm (0 in) for February, March, April, and May, respectively). At the end of the study period (May 7, 2007), seedling survival was recorded.

Study III: Root Growth Potential. The gel and clay treatments for this study were the same as above (table 1). After root treatments had been applied, the seedlings were exposed for 1, 2, or 4 h. Greenhouse temperatures ranged from 29 to 33 °C (84.2 to 91.4 °F); relative humidity ranged from 18 to 42 percent. The average solar radiation within the greenhouse during the study was 20,500 lumen m^{-2} (1,900 lux).

The trial used two seedlings per experimental unit, with 18 replications (a total of 36 seedlings per treatment-exposure); 15 experimental units were contained in one aquarium (5 treatments × 3 exposure times). Seedling roots were suspended in aerated water, and water level in each aquarium was adjusted daily. After 4 wk, the numbers of new white root tips on each seedling were counted.

Data from each study were analyzed by analysis of variance (ANOVA) for a randomized complete block design. When the F-test for treatment was significant (α=0.05), treatment means were separated using Duncan's New Multiple Range Test. The SPSS® software (SPSS Inc, Chicago, IL, spss.com) was used for all data analysis.

Results

Study I: fungal growth. Particle size varied considerably among the gel treatments. PAM gel "A" had a greater percentage of large particles, while the CSB gel had a greater percentage of fine material (table 1). The water agar control was the baseline for each fungus tested. Therefore, any growth less than that observed in control plates indicated an inhibitory effect on the fungus (table 2), whereas more growth than in the controls indicated that the fungus was able to use the amendment as a food source. *Rhizoctonia* grew the fastest, with one or more treatments reaching the edge of the petri plate before day 6.

In all cases, clay inhibited fungal growth. All of the gel treatments inhibited growth of *Pythium* sp., but the clay treatment had the greatest effect. There was more plate-to-plate variation with the *Pythium* sp. than the other fungi. The growth of *Fusarium* sp. on the CSB gel was greater than for the control plates; clay was the only inhibitory treatment. Growth of *Rhizoctonia* sp. was increased by all the gels.

Study II: seedling survival following exposure. Treatments significant affected seedling survival, but there were no differences among treatments with 0 or 1 h of exposure (table 3). The root gels increased survival after 2 or 4 h of exposure. Clay or water dips, however, did not protect the roots exposed to these longer times of desiccation. This is very evident at 4 h of exposure, where the gel treatments increased survival by 40 percentage points or more.

Table 2. Fungal growth (mm) on amended or unamended water agar medium.

Amendment	*Pythium* (Day 6)	*Fusarium* (Day 6)	*Rhizoctonia* (Day 4)
Clay	10d	51c	58c
PAM gel "A"	26c	60b	75a
PAM gel "B"	31c	60b	74a
CSB gel	42b	63a	76a
Control	69a	61b	70b
$lsd_{(0.05)}$	6.5	1.6	2.8

[1] Means in columns followed by the same letter are not significantly different (=0.05; Duncan's new multiple range test).

Table 3. Loblolly pine survival (percent) after 3 mo, as affected by root dip treatment and length of exposure.

Dip treatment	Length of exposure (h)			
	0	1	2	4
PAM gel "B"	94.5a	86.8a	87.0b[1]	60.0b
PAM gel "A"	82.6a	88.9a	93.5b	56.1b
CSB gel	79.2a	76.2a	85.9b	52.8b
Clay	91.2a	87.9a	52.9a	12.1a
Water	97.8a	85.7a	77.2ab	12.1a

[1] Means in columns followed by the same letter are not significantly different (=0.05; Duncan's new multiple range test).

Study III: root growth potential. The root growth potential (RGP) study showed similar trends as the survival study. In the water-only treatment, 1 h of exposure reduced RGP by half, compared with the clay or CBS gel. In both the 2- and 4-h desiccation treatments, the RGP was reduced to fewer than 4 roots in both the clay and water treatments (table 4). Even when placed in water, the desiccated roots were not able to recover and produce new root tips. The gels provided some protection during the extended desiccation periods.

Discussion

When seedlings are handled carefully, not exposed to drying conditions, and not stored, outplanting survival can be greater than 80 percent (Venator and Brissette 1983). Under ideal conditions, roots would never be exposed to 2–4 hours of desiccation and would always be planted in moist soil. However, nursery managers typically have no control of seedling care after stock is shipped from the nursery. Every nursery manager has a file full of examples of seedlings transported incorrectly, stored in the sun at the planting site, and handled incorrectly by the planting crew.

Many studies have exposed roots after treatment with clay or gels (Slocum and Maki 1956; Williston 1967; Miller and Reines 1974; Dierauf and Gardner 1975; Alm and Stanton 1993). In this study, we decided to subject treated seedlings to various times of desiccation and then transplant them into moist sand to allow seedlings to become established.

Results from the survival and RGP studies agreed, but the RGP test detected treatment differences after just 1 h of desiccation. Our data agree with those of others who found that gels provided an increase in survival (Echols and others 1990; Alm and Stanton 1993). Although clay was not effective in preventing permanent root damage to the seedlings in our study, clay did improve seedling survival in a previous study (Slocum and Maki 1959).

During the 1980s, there were concerns that fermentation of wood fiber mulches or starch gels would result in deterioration of seedlings stored in the shade (Barnard and others 1981). The concern was that the wood fibers (or starch) were providing a substrate for pathogenic microbes. Therefore, some nursery managers have expressed a concern that root gels, especially the starch-based gels, could support the growth of soil-borne fungi. In order for disease to develop, three factors must occur. First, the environment must be conducive to disease development (this generally means optimal moisture and temperature). Second, the host must be susceptible. In some cases, the host may be too old to be susceptible. Third, you must have a virulent pathogen.

Of the four root dips tested, kaolin clay was the only treatment that did not support, but in fact inhibited, the growth of the three soil-borne fungi tested. The other root dips tested stimulated fungal growth, especially of *Fusarium sp.* and *Rhizoctonia sp*. Since these are common nursery fungi, they could utilize the polyacrylamide hydrogels or the cornstarch-based hydrogel as a food source. Thus, the gels might have negative ramifications during seedling storage, especially the CSB gel in the presence of *Fusarium sp*.

In many cases, a researcher wants to see significant differences among treatments before making a recommendation. In fact, many researchers do not even consider the benefit/cost ratio of a treatment if the treatment is significant at α=0.15. In many outplanting trials, researchers cannot declare a 10 percent or more increase in seedling survival as statistically significant, due to trials with low statistical power. For example, in one root-treatment trial in Louisiana, a 50 percent increase in survival was not statistically significant (Venator and Brissette 1982). Therefore, some might say that a treatment that is not "statistically signifi-

Table 4. Average number of white root tips at 4 wk, as affected by root dip treatment and length of exposure.

Treatment	Length of exposure		
	1 h	2 h	4 h
PAM gel "B"	32.1ab[1]	29.3b	19.9a
PAM gel "A"	41.3a	16.8c	22.6a
CBS gel	45.3a	39.3a	14.9a
Clay	43.1a	1.2d	0.0b
Water	22.0b	3.4d	0.0b

[1] Means in columns followed by the same letter are not significantly different (=0.05; Duncan's new multiple range test).

cant" but consistently increases survival by 5 percent is not worth the cost, even though it costs only pennies per acre.

Nursery managers have a different view. They may want to know if an inexpensive treatment provides some "insurance" against adverse conditions (Alm and Stanton 1993). At one site in Texas (Kroll and others 1984), treating loblolly pine with a gel increased survival from 19.6 to 50.8 percent and survival of slash pine was increased from 16.9 to 20.8 percent. In the loblolly pine case, the savings might be \$500 ha^{-1} (cost of replanting) and the cost of the gel treatment might be 7.5 cents ha^{-1}. This equals a cost benefit ratio of 6,666 (i.e., \$500/\$0.075). If preventing a replant was very rare (say 1 ha out of 6,666), the cost of the treatment (\$500 per 6.6 million seedlings) would equal the benefit (e.g., \$500). If the gel treatment reduced replanting by only 1 ha in 3,333, the benefit/cost ratio might equal 2 (e.g., \$500/\$250). As a comparison, Echols and others (1990) reported an increase in survival in 1 out of 3 sites. Therefore, some nursery managers believe the use of gels makes sense both economically and from a "marketing" perspective.

Management Implications and Conclusions

When freshly lifted seedlings were exposed for 1 h, some protection (as measured by RGP) was provided by both the kaolin clay and the PAM gel root dip treatments. When seedlings were exposed 2 h or more, only the gel root dip treatments increased seedling survival and RGP. Thus, continued use of gel root dip treatments by nursery managers as "insurance" against poor handling after seedlings leave the nursery is worth the cost of the materials. Kaolin clay inhibited all three soil-borne fungi, whereas gel-based root dips increased growth of *Rhizoctonia* sp. In all cases, treating loblolly pine roots with root gels kept short roots alive so they could elongate when placed into a favorable environment.

Results from these studies are applicable only when seedlings are transplanted within a few days of treatment. Additional research is required to determine if gels affect fungal growth during long-term, cool storage (e.g., 1 degree above freezing) of seedlings.

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Constructing an Inexpensive Weather Station Pole

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Abstract

Weather stations are commonly employed in outdoor research programs, but they can be very expensive. A weather station pole is presented here that accomplishes the same function as one sold commercially, yet is half as expensive. Step-by-step instructions, pictures, a schematic, and parts and tools lists are included.

Introduction

Today's electronic sensing equipment makes it relatively simple to establish onsite weather stations. Researchers often use these sensors to collect detailed site-specific environmental information, but the sensors and the structural equipment necessary to position them can be very expensive. Small savings are often required throughout the research process in order to balance the rigors of science with budgetary constraints. Although the environmental sensors themselves have unavoidable associated costs, money can be saved on the structure used to hold these sensors.

This paper describes a simple weather station pole (figure 1) that was developed to allow the secure attachment of environmental sensors, utilizing the mounting hardware provided by the company while reducing the overall price tag. All of the necessary equipment for the pole was purchased at local hardware stores. This pole can be adapted to a variety of situations, sensor types, and configurations for use with environmental sensing equipment from different manufacturers.

As an example of the potential savings, the Vegetation Management Research Cooperative (VMRC) initiated five new study sites in 2006 and 2007. Each site had a centrally located weather station that included a rain gauge, an air temperature/relative humidity sensor, a wind speed indicator, and a light meter. Some manufacturers charge as much as $165 for a 6-ft (1.8-m) weather station tripod system. The weather station pole presented here cost less than half that amount, saving the VMRC over $445 during those 2 yr.

Figure 1. A weather station in the field.

Instructions

The schematic of the weather pole (figure 2) can be used for reference during assembly.

Before heading into the field:

1. Order the environmental sensing equipment and the necessary mounting hardware for each sensor.
2. Obtain other supplies and equipment locally (tables 1 and 2). (Adjustments to the fence-pipe diameter may be needed if the attachment hardware is a different size.)

3. If the weather station will be installed on a particularly rocky site, use a heavier gauge pipe (galvanized steel). Note: this will increase the cost of the pole.

4. Drill three ¼-in (7-mm) holes through the fence pipe (A, figure 2) 120° apart and approximately 3 ft (1 m) from the top of the pole (guy wire detail, figure 2). Make sure the holes are 1 in (2.54 cm) apart *vertically* so that the 4-in (10-cm)-long eyebolts (E) do not interfere with each other as they pass through the fence pipe (figure 3).

5. If a wind speed arm will be attached, drill the necessary holes 2 in (5 cm) from the top of the fence pipe (figure 4). Leaving 2 in (5 cm) at the top of the pipe will allow the rain gage to be mounted so that it is above the height of the fence pole. The pipe clamps for the rain gage will be positioned above and below where the wind speed arm attaches (figure 4).

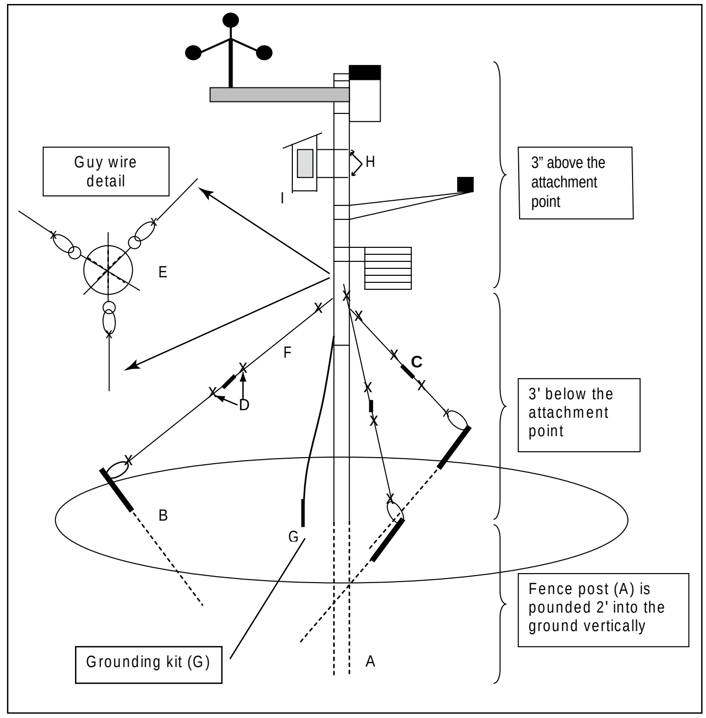

Figure 2. Weather station schematic.

Table 1. Equipment list.

Symbol[1]	Equipment	Size	Number needed	Cost (US$)	Total cost (US$)
A	Line post (fence)	8 ft long, 1½-in diameter	1	9.00	9.00
B	Galvanized pipe	3 ft long, ¾-in diameter	3	3.69	11.07
C	Turnbuckle	5½ in long, ¼ diameter	3	1.10	3.30
D	U-bolt cable connector	in	12	0.50	6.00
E	Eyebolt	4 in long, ¼-in diameter	3	0.50	1.50
F	Cable	3-ft length, -in diameter	6	0.57	3.42
G	Ground wire kit[2]		1	35.00	35.00
H	U-bolt connector	¼ by 1 in	2	1.50	3.00
I	Scrap plywood	12 by 16 in, ½-in thick	1	3.00	3.00
				Total	75.29

[1] Refers to symbols on figure 1.

[2] A ground wire kit normally consists of a copper stake that is driven in the ground near the fence post pipe (A). A length of copper wire is then attached with one end to the fence post pipe (A) and the other to the copper stake.


Figure 3. Guy wire attachment.

Table 2. Tools required.

Electric drill with ¼-in (7 mm) drill bit
Fence post pounder or sledge hammer
Ratchet set
Adjustable wrench
Screw driver
2-ft (60 cm) carpenter level

6. Drill ¼-in (7-mm) holes 2 in (5 cm) from the top of each piece of ¾-in (1.9-cm) diameter pipe (B).

Once in the field, finish the assembly.

1. Pound the fence pipe (A) into the ground in the desired location. Use the 2-ft (60-cm) carpenter's level periodically to ensure that the pole stays relatively vertical. Small adjustments will be accomplished with the turnbuckles (C) later.

2. Install the three eyebolts (E) into the fence pipe as shown in figures 2 and 3.

3. Pound the 3-ft (91-cm) lengths of pipe (B) with the ¼-in (7-mm) holes on top into the ground approximately 3 ft (1 m) from the base of the fence pipe. Make sure that they are in line with the eyebolts on the fence pipe, canted at a 20–30^o angle; leave the upper 6 in (15 cm) exposed. Canting the pipes will allow them to maximize their holding power as stakes when tension is applied with the turnbuckles (figure 5).

4. Attach one length of 1/8-in (3-mm) cable (F) to each eyebolt (E), using 1/8-in (3-mm) cable connectors (D).

Figure 4. Wind speed arm attachment point.

5. Attach a turnbuckle (C) to the other end of these pieces of 1/8-in (3-mm) cable with a second cable connector (D) (figure 6).

6. Insert lengths of 1/8-in (3-mm) cable (F) into the holes drilled on the top of each of the 3-ft (91-cm) stakes (B) and attach them with cable connectors (D) close to the stakes (figure 5).

Figure 5. Stake attachment.

Figure 6. Turnbuckle attachment.

7. Attach the other end of these cables to the turnbuckles with another cable connector (D), completing the guy wire assemblies. Carefully take out the slack of each guy wire as you tighten these last cable connectors. Be sure to check that the pole is still vertical during this process.

8. Lastly, tighten the turnbuckles on each guy wire frequently checking the fence pipe for a vertical orientation with the level in at least two directions. This is a trial-and-error process, but the guy wires, once tight, will provide stability and allow small adjustments when necessary.

Attaching the equipment:

1. Attach the weather station equipment following the directions provided by the manufacturer. It is important to electrically ground this pole, so use an appropriate grounding wire kit (G).

2. Drill two ¼-in (7-mm) holes 1 in (2.54 cm) from the top and bottom of the scrap of plywood (I) to allow the U-bolt connectors (H) to pass through. Then use the two 1⅝-in (4 cm) U-bolt connectors (H) to attach the plywood (I) to the pole (figure 2).

3. Mount the data recording device to the plywood (I), following all instructions.

4. If extra weatherproofing for the data-recording device is needed, consider making a small awning with scrap plywood and covering it with plastic wrap or roofing material (figure 1). Hinged plastic boxes or ammunition cans mounted to the plywood backing (I) also work very well.

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Forest Tree Seedling Production in the Southern United States: The 2005–2006 Planting Season

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Abstract

This report summarizes nursery forest seedling production in the Southern United States for the 2005–2006 planting season. Seedling production is presented by nursery ownership class, seedling type (container or bareroot), and species grown. Survey data report 964,532,000 bareroot and 36,268,000 container-grown conifer seedlings for a total conifer production of 1,000,800,000. Total hardwood seedling production for the 12 States surveyed was 44,866,000, of which 38,816,000 were bareroot and 6,050,000, container grown. Total conifer and hardwood seedling production for the Southern United States in 2005–2006 was 1,045,666,000 seedlings. Seedling production and acres planted in 2004–2006 are compared with figures for the 1997–1998 planting seasons reported by the Forest Service for the region. Seedling production across the Southern United States is down 19 percent (254 million seedlings) from the 1997 planting season. It could be inferred from these figures that reforestation in the region has decreased correspondingly.

Introduction

In the past, the Forest Service has collected seedling production and planting information and made this information public through publishing in *Tree Planters' Notes*. Unfortunately, the Forest Service has not been able to publish this information for several years. In order to obtain an idea of current seedling production in the South, the Auburn University Southern Forest Management Nursery Cooperative began surveying nursery managers in the region to determine production numbers for the previous planting seasons. What follows is the information on seedling production returned for the December 2005 to March 2006 planting season.

Methods

Data were obtained through a questionnaire mailed in June 2006 to 99 nurseries in 12 Southern States: Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia. The two-page questionnaire asked for production (not sales) for the 2005–2006 nursery season for the conifer and hardwood tree species produced by each organization. Only nurseries with an estimated production above 500,000 bareroot or container seedlings were surveyed. We attempted to contact all such nurseries, regardless of affiliation or ownership, including those not associated with the Nursery Cooperative. The mail survey was followed up by phone contact until all nurseries were accounted for. Responses were received from 57 nurseries. This was a decline from the 66 nurseries reporting in a similar survey in 2005, but similar to the 56 nurseries reporting in 2004.

Results

Conifer Seedling Production. Data compiled from the returned surveys indicated that 964,532,000 bareroot and 36,268,000 container-grown conifer seedlings were produced during the 2005–2006 season, for a total conifer production of 1.0008 billion (tables 1–3). Compared with the previous year, the 2005–2006 production decreased 10.9 percent in bareroot and increased 2.2 percent in container-grown seedling production, with an overall regional decrease from 1.1096 billion to 1.0008 billion conifer seedlings. Loblolly pine (*Pinus taeda*) was by far the most commonly grown tree species in the region, accounting for 82 percent of all conifer seedlings produced, followed by slash pine (*P. elliottii*), at 13 percent, and longleaf pine (*P. palustris*), at 3 percent. These three conifer species accounted for 98 percent of all conifer production in the region. Bald cypress (*Taxodium distichum*) was the fourth most important species in terms of production (0.38 percent), followed by white pine (*Pinus strobus*), sand pine (*P. clausa*), shortleaf pine, (*P. echinata*), Fraser fir (*Abies fraseri*), and Virginia pine (*Pinus virginiana*) (table 3). Interestingly, bald cypress was the only conifer grown in all 12 States surveyed. Only 3.6 percent of all conifer production was grown in containers, 64 percent of which was longleaf pine. Seventy percent of all longleaf pine production was container-grown, an increase of 7 percent from last year (63 percent).

All surveyed States produced conifer nursery stock, ranging from 185 million in Georgia to about 0.5 million in Oklahoma. Georgia produced 37 percent of all container-grown conifer planting stock in the region. In terms of total conifer, the order was (1) Georgia, (2) South Carolina, (3) Alabama, (4) Texas, (5) Arkansas, (6) Mississippi, (7) North Carolina, (8) Florida, (9) Virginia, (10) Louisiana, (11) Tennessee, and (12) Oklahoma (table 3).

Hardwood Seedling Production. Total hardwood seedling production (tables 4–6) for the 12 States surveyed was 44,864,000. This was a decrease of 12 million trees (21 percent) from the 2004–2005 seedling production survey. This reduction is most likely due to a decrease in region-wide production, as well as a lack of survey participation by hardwood nurseries. *Quercus* spp. was by far the most important genus, comprising 56 percent of all hardwood production reported. This is followed by the “others” category (26 percent), green ash (*Fraxinus americana*) (5 percent), sweetgum (*Liquidambar styraciflua*) (2 percent), flowering dogwood (*Cornus florida*) (1.6 percent), pecan (*Carya illinoensis*) (1 percent), yellow-poplar (*Liriodendron tulipifera*) (1 percent), sycamore (*Platanus occidentalis)* (2 percent), black walnut (*Juglans nigra*) (0.7 percent), and cottonwood (*Populus deltoides*) (0.4 percent). Hardwoods were grown in all States surveyed, ranging from 10.6 million in Arkansas to 1.1 million in Alabama. The top five hardwood-producing States in the region, in descending order, were Arkansas, Virginia, South Carolina, Louisiana, and Georgia.

Production by Ownership Category. The majority of regional seedling production occurred in industrial nurseries (68 percent), with State nurseries providing 18 percent of seedling supplies and private nurseries growing 14 percent (tables 7–10). A “private” nursery is privately owned but not part of an organization or company that operates a wood-processing facility—i.e., “nonindustrial.” There was little change from the 2004–2005 survey in terms of the proportion of total seedling production by owner category.

Private nurseries produced 50 percent of container-grown conifer planting stock in the region, followed by industrial (30 percent), and state-owned (20 percent). Industry increased its proportion of conifer container production from 20 percent to 30 percent from the 2004–2005 season to the 2005–2006 season, while private nurseries decreased their proportion from 62 percent to 50 percent.

State Ranking and Changes from 2004–2005 Survey. A State-by-State ranking is provided in table 11. The decline in seedling production is distributed across the growing region. Only Virginia and Arkansas increased seedling production in the region. Caution should be used when interpreting these data, as a large percentage change in an individual State does not necessarily indicate a large change in regional production. The most significant reduction occurred in Georgia, where the nurseries produced 83 million fewer seedlings than in the previous year.

Nursery Cooperative Member Seedling Production. Members of the Nursery Cooperative continue to lead the region in bareroot seedling production, with 86 percent of all bareroot production in the Southern United States associated with the Nursery Cooperative (table 12). This amount is about 8 percent higher than reported for the 2004–2005 production season (McNabb 2005). Nursery Cooperative members accounted for 30 percent of container production, up slightly from the 27 percent reported last year. Members of the Nursery Cooperative produce 83 percent of all seedlings in the region.

Table 1. Bareroot conifer seedling production (×1000) by State for the 2005–2006 planting season across the South.

State	Bald cypress		Fraser fir		Loblolly pine		Longleaf pine		Sand pine		Shortleaf pine		Slash pine		Virginia pine		White pine		Total	
	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[b]
AL	83	0			133,307	93	778	1	300	0			9,405	7	27	0			143,900	15
AR	990	1			100,593	98					582	1							102,165	11
FL	840	2			5,400	11	5,675	11	790	2			38,070	75	65	0			50,840	5
GA	102	0			112,934	66	1,350	1	957	1	172	0	55,625	32	215	0			171,355	18
LA	255	1			20,645	70	300	1					8,313	28	50	0			29,563	3
MS	311	0			94,701	99							665	1					95,677	10
NC	103	0	1,500	3	55,400	94	176	0			580	1			80	0	1,000	2	58,839	6
OK	80	19			5	1					200	47			140	33			425	0
SC	63	0			151,731	96	1,688	1			15	0	4,022	3	89	0	171	0	157,779	16
TN	127	2			4,439	82					160	3			62	1	655	12	5,443	1
TX	190	0			106,029	92					80	0	8,344	7	263	0			114,906	12
VA	52	0			30,857	92					366	1			423	1	1,942	6	33,640	3
Region	3,196	0	1,500	0	816,041	85	9,967	1	2,047	0	2,155	0	124,444	13	1,414	0	3,768	0	964,532	

[a] Percent of State production.

[b] Percent of regional production.

Table 2. Container-grown conifer seedling production (×1000) by State for the 2005–2006 planting season across the South. No container-grown white pine was produced in the region during this period.

State	Bald cypress		Fraser fir		Loblolly pine		Longleaf pine		Sand pine		Shortleaf pine		Slash pine		Virginia pine		Total	
	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[b]
AL	2	0			3,101	43	3,856	53			170	2	40	1	110	2	7,279	20
AR					75	100											75	0
FL							3,349	98	13	0			60	2			3,422	9
GA	100	1			2,750	20	8,226	61	1,050	8			1,340	10			13,466	37
LA							400	100									400	1
MS							494	100									494	1
NC			220	3	3,466	42	4,640	56									8,326	23
OK					24	89									3	11	27	0
SC	519	31			1	0	1,140	69									1,660	5
TN																	0	0
TX	6	1			1	0	1,012	99									1,019	3
VA							100	100									100	0
Region	627	2	220	1	9,418	26	23,217	64	1,063	3	170	0	1,440	4	113	0	36,268	

[a] Percent of State production.

[b] Percent of regional production.

Table 5. Container-grown hardwood seedling production (×1000) by State for the 2005–2006 planting season across the South. There was no container-grown walnut production during this period.

State	Cottonwood		Dogwood		Green ash		Oak		Pecan		Sweetgum		Sycamore		Yellow-poplar		Others		Total	
	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[b]
AL			1	5	2	9	8	36							1	5	10	45	22	1
AR																				
FL																	1,036	100	1,036	17
GA			10	1			350	52	5	1	100	15	10	1			200	30	675	11
LA																				
MS																				
NC					2	17											10	83	12	1
OK																				
SC																	30	100	30	1
TN																				
TX	1	0					50	20	2	1	1	0	1	0			200	78	255	4
VA			1,310		440		1,220				640		410						4,020	66
Region	1	0	1,321	21	444	7	1,628	27	7	0	741	12	421	7	1	0	1,486	25	6,050	

[a] Percent of State production.
[b] Percent of regional production.

Table 6. Hardwood seedling production (×1000) by State for the 2005-2006 planting season across the South.

State	Cottonwood		Dogwood		Green ash		Oak		Pecan		Sweetgum		Sycamore		Walnut		Yellow-poplar		Others		Total	
	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[b]
AL			9	1	11	1	883	74			13	1					17	1	253	21	1,186	2
AR	58	1	2	0	541	5	8,001	75	147	1	125	1			50	0	37	0	1,675	16	10,636	24
FL			50	3	50	3	400	21			100	5	50	3					1,287	66	1,937	4
GA			87	2	47	1	2,780	69	5	0	200	5	20	0			28	1	838	21	4,005	9
LA	99	2			367	9	3,229	78	185	4	4	0	72	2	16	0			193	5	4,165	9
MS					195	9	2,013	89											65	3	2,273	5
NC			70	4	34	2	976	62					21	1	40	3	48	3	386	25	1,575	3
OK			30	2	67	5	190	15	75	6			25	2	75	6			780	63	1,242	3
SC			85	2	103	2	1,780	32	19	0	107	2	148	3	2	0	128	2	3,138	57	5,510	12
TN			15	1	143	9	861	56	47	3	26	2	10	1	61	4	116	8	258	17	1,537	3
TX	1	0	27	1	160	7	1,351	61	91	4	57	3	1	0	35	2	20	1	473	21	2,216	5
VA			1,594	19	706	8	2,629	31			705	8	522	5	26	1	132	1	2,270	26	8,584	19
Region	158	1	1,969	4	2,424	5	25,093	56	569	1	1,337	2	869	2	305	1	526	1	11,616	26	44,866	

[a] Percent of State production.
[b] Percent of regional production.

Table 7. Species production (×1000) and percent of species production by each ownership class for the 2005–2006 planting season across the South by ownership category.

Type	Species	State		Private[a]		Industry[b]		Total
		Seedlings	%	Seedlings	%	Seedlings	%	Seedlings
Conifer								
Bareroot	Bald cypress	2,065	65	626	20	505	16	3,196
	Fraser fir	1,500	100					1,500
	Loblolly pine	116,877	14	67,954	8	631,210	77	816,041
	Longleaf pine	6,826	68	2,243	23	898	9	9,967
	Sand pine	290	14	500	24	1,257	61	2,047
	Shortleaf pine	2,051	95			104	5	2,155
	Slash pine	25,035	20	48,169	39	51,240	41	124,444
	Virginia pine	1,099	78	107	8	208	15	1,414
	White pine	3,768	100					3,768
	TOTAL	159,511	17	119,599	12	685,422	71	964,532
Container	Bald cypress	3	0	105	17	519	83	627
	Fraser fir	220	100					220
	Loblolly pine	491	5	3,852	41	5,075	54	9,418
	Longleaf pine	6,473	28	11,406	49	5,338	23	23,217
	Sand pine	13	1	1,050	99			1,063
	Shortleaf pine			170	100			170
	Slash pine	60	4	1,290	90	90	6	1,440
	Virginia pine	3	3	110	97			113
	White pine							
	TOTAL	7,263	20	17,983	50	11,022	30	36,268
Hardwood								
Bareroot	Cottonwood	99	63			58	37	157
	Dogwood	495	76	97	15	56	9	648
	Green ash	1,443	73	188	9	349	18	1,980
	Oak	13,500	58	2,202	9	7,763	33	23,465
	Pecan	391	70	74	13	97	17	562
	Sweetgum	130	22	115	19	351	59	596
	Sycamore	239	53	60	13	149	33	448
	Walnut	295	97	10	3			305
	Yellow-poplar	328	62	31	6	166	32	525
	Others	5,787	58	751	7	3,592	35	10,130
	TOTAL	22,707	59	3,528	9	12,581	32	38,816
Container	Cottonwood			1	100			1
	Dogwood			1,321	100			1,321
	Green ash			442	100			442
	Oak	1	1	1,627	99			1,628
	Pecan			2	100			2
	Sweetgum			745	100			745
	Sycamore			422	100			422
	Yellow-poplar			1	100			1
	Others	1,076	72	410	27			1,486
	TOTAL	1,077	18	4,977	82			6,050

[a] Nurseries owned by companies or individuals that do not own wood-processing facilities.

[b] Nurseries owned by companies that have wood-processing facilities.

Table 3. Conifer seedling production (×1000) by State for the 2005–2006 planting season across the South.

State	Bald cypress		Fraser fir		Loblolly pine		Longleaf pine		Sand pine		Shortleaf pine		Slash pine		Virginia pine		White pine		Total	
	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[b]
AL	85	0			136,408	90	4,634	3	300	0	170	0	9,445	6	137	0			151,179	15
AR	990	1			100,668	98					582	1							102,240	10
FL	840	2			5,400	10	9,024	17	803	1			38,130	70	65	0			54,262	5
GA	202	0			115,684	63	9,576	5	2,007	1	172	0	56,965	31	215	0			184,821	18
LA	255	1			20,645	69	700	2					8,313	28	50	0			29,963	3
MS	311	0			94,701	98	494	1					665	1					96,171	10
NC	103	0	1,720	3	58,866	88	4,816	7			580	1			80	0	1,000	1	67,165	7
OK	80	18			29	6	0	0			200	44			143	32			452	0
SC	582	0			151,732	95	2,828	2			15	0	4,022	3	89	0	171	0	159,439	16
TN	127	2			4,439	82	0	0			160	3			62	1	655	12	5,443	1
TX	196	0			106,030	91	1,012	1			80	0	8,344	7	263	0			115,925	12
VA	52	0			30,857	91	100	0			366	1			423	1	1,942	6	33,740	3
Region	3,823	0	1,720	0	825,459	82	33,184	3	3,110	0	2,325	0	125,884	13	1,527	0	3,768	0	1,000,800	

[a] Percent of State production.

[b] Percent of regional production.

Table 4. Bareroot hardwood seedling production (×1000) by State for the 2005–2006 planting season across the South.

State	Cottonwood		Dogwood		Green ash		Oak		Pecan		Sweetgum		Sycamore		Walnut		Yellow-poplar		Others		Total	
	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[a]	Seedlings	%[b]
AL			8	1	9	1	875	75			13	1					16	1	243	21	1,164	3
AR	58	1	2	0	541	5	8,001	75	147	1	125	1			50	0	37	0	1,675	16	10,636	27
FL			50	6	50	6	400	44			100	11	50	6					251	28	901	2
GA			77	2	47	1	2,430	73			100	3	10	0			28	1	638	19	3,330	9
LA	99	2			367	9	3,229	78	185	4	4	0	72	2	16	0			193	5	4,165	11
MS					195	9	2,013	89											65	3	2,273	6
NC			70	4	32	2	976	62					21	1	40	3	48	3	376	24	1,563	4
OK			30	2	67	5	190	15	75	6			25	2	75	6			780	63	1,242	3
SC			85	2	103	2	1,780	32	19	0	107	2	148	3	2	0	128	2	3,108	57	5,480	14
TN			15	1	143	9	861	56	47	3	26	2	10	1	61	4	116	8	258	17	1,537	4
TX			27	1	160	8	1,301	66	89	5	56	3			35	2	20	1	273	14	1,961	5
VA			284	6	266	6	1,409	31			65	1	112	2	26	1	132	3	2,270	50	4,564	12
Region	157	0	648	2	1,980	5	23,465	60	562	1	596	2	448	1	305	1	525	1	10,130	26	38,816	

[a] Percent of State production.

[b] Percent of regional production.

Table 8. Conifer seedling production (×1000) for the 2005–2006 planting season across the South by ownership category. Percents are calculated for each stock type within a State.

State	Bareroot						Container						Total production						
	State	%	Private[a]	%	Industry[b]	%	State	%	Private[a]	%	Industry[b]	%	State	%	Private[a]	%	Industry[b]	%	Total
AL			35,574	24	108,326	72			4,179	3	3,100	2			39,753	26	111,426	74	151,179
AR	7,250	7			94,915	93					75	0	7,250	7			94,990	93	102,240
FL	11,200	21	39,640	73			3,422	6					14,622	27	39,640	73			54,262
GA	19,625	11	39,165	21	112,565	61			12,650	7	816	0	19,625	11	51,815	28	113,381	61	184,821
LA	29,563	99							400	1			29,563	99	400	1			29,963
MS	16,650	17			79,027	82	494	1					17,144	18			79,027	82	96,171
NC	13,839	21			45,000	67	2,326	3			6,000	9	16,165	24			51,000	76	67,165
OK	425	94					27	6					452	100					452
SC	5,661	4			152,118	95	391	0	750	0	519	0	6,052	4	750	0	152,637	96	159,439
TN	5,423	100	20	0									5,423	100	20	0			5,443
TX	16,235	14	5,200	4	93,471	81	503	0	4	0	512	0	16,738	14	5,204	4	93,983	81	115,925
VA	33,640	100					100	0					33,740	100					33,740
Region	159,511	16	119,599	12	685,422	68	7,263	1	17,983	2	11,022	1	166,774	17	137,582	14	696,444	70	1,000,800

[a] Nurseries owned by companies or individuals that do not own wood-processing facilities.

[b] Nurseries owned by companies that have wood-processing facilities.

Table 9. Hardwood seedling production (×1000) for the 2005–2006 planting season across the South by ownership category. Percents are calculated for each stock type within a State. No container seedlings were produced in industrial nurseries.

State	Bareroot						Container				Total production						
	State	%	Private[a]	%	Industry[b]	%	State	%	Private[a]	%	State	%	Private[a]	%	Industry[b]	%	Total
AL			861	73	303	26			22	2			883	74	303	26	1,186
AR	5,850	55			4,786	45					5,850	55			4,786	45	10,636
FL			900	46			1,038	54			1,037	54	900	46			1,937
GA	716	18	310	8	2,304	58			675	17	716	18	985	25	2,304	58	4,005
LA	4,165	100									4,165	100					4,165
MS	1,841	81			432	19					1,841	81			432	19	2,273
NC	1,563	99					12	1			1,575	100					1,575
OK	1,242	100									1,242	100					1,242
SC	1,244	23			4,225	77	30	1			1,285	23			4,225	77	5,510
TN	1,067	69	470	31							1,067	69	470	31			1,537
TX	445	20	986	44	530	24	1	0	255	12	445	20	1,241	56	530	24	2,217
VA	4,564	100							4,021	100	4,564	53	4,021	47			8,577
Region	22,707	50	3,527	7	12,580	28	1,080	2	4,972	11	23,787	53	8,549	19	12,580	28	44,866

[a] Nurseries owned by companies or individuals that do not own wood-processing facilities.

[b] Nurseries owned by companies that have wood-processing facilities.

Table 10. Seedling production (×1000) for the 2005–2006 planting season across the South by ownership category.

State	Total seedling production							
	State	%[a]	Private[b]	%[a]	Industry[c]	%[a]	Total	%[d]
AL			40,636	27	111,729	73	152,365	15
AR	13,100	12			99,776	88	112,876	11
FL	15,659	28	40,540	72			56,199	5
GA	20,341	11	52,800	28	115,685	61	188,826	18
LA	33,728	99	400	1			34,128	3
MS	18,985	19			79,459	81	98,444	9
NC	17,740	26			51,000	74	68,740	7
OK	1,694	100					1,694	0
SC	7,337	4	750	0	156,862	95	164,949	16
TN	6,490	93	490	7			6,980	1
TX	17,183	15	6,445	5	94,513	80	118,141	11
VA	38,304	90	4,021	10			42,325	4

[a] Percent of State production.
[b] Nurseries owned by companies or individuals that do not own wood-processing facilities.
[c] Nurseries owned by companies that have wood-processing facilities.
[d] Percent of regional production.

Table 11. Percent change in seedling production from the 2004–2005 to the 2005–2006 nursery season.

State	2004–2005 production (millions)	Rank	Change	2005–2006 production (millions)	Rank
AL	175	2	– 13	152	3
AR	103	6	+ 10	113	5
FL	58	8	– 3	56	8
GA	272	1	– 30	189	1
LA	38	9	– 10	34	10
MS	112	5	– 13	98	6
NC	70	7	– 1	69	7
OK	3	12	– 33	2	12
SC	168	3	– 2	165	2
TN	13	11	– 46	7	11
TX	120	4	– 2	118	4
VA	34	10	+ 19	42	9

Table 12. Auburn University Southern Forest Nursery Management Cooperative representation in regional seedling production (×1000).

Type and source of production	Total production	Proportion	
		of source	of total
Bareroot			
Nursery Cooperative members	860,170	85.7	82.2
Nonmembers	143,175	14.3	13.8
Total Bareroot	1,003,346		95.9
Container			
Nursery Cooperative members	12,801	30.2	1.2
Nonmembers	29,519	69.8	2.4
Total Container	42,320		4.1
All			
Nursery Cooperative members	872,972		83.4
Nonmembers	172,695		16.6
Total	1,045,664		

Discussion

Seedling production across the South for the 2005–2006 planting season was 1.045 billion seedlings, a decrease of 121 million (10.4 percent) from the 2004–2005 planting season (McNabb 2005). The vast majority (90 percent) of reduction in seedling production from 2004 were bareroot loblolly and slash pine. Hardwoods were 3.7 percent of regional seedling production, a decrease of 1.2 percent from the 2004 planting season. A total of 3.7 percent of all seedlings were container-grown, with longleaf pine being a majority of this production.

One of the shortcomings of this particular survey tool is that the numbers reported do not necessarily translate into acres planted within each state surveyed or by landownership category. Data are collected as production, so information on actual seedling sales or seedlings planted by State or landownership category is not available. What these numbers do provide is a pretty good estimate of seedlings (species, planting stock, etc.) that probably were planted by nonindustrial landowners, forest industry, Real Estate Investment Trusts, or Timber Investment Management Organizations during the 2005–2006 planting season. A simple estimate of the acres planted across the region could be made by dividing the number of seedlings produced by 600 seedlings per acre for a total of 1,742,778 acres planted. While this figure is close to the acres reported in the *Tree Planters' Notes* annual report (table 13), it is about 15 percent less than what was reported for the 1997 season. With about 254 million fewer seedlings produced in 2005 than 1997, one could infer a corresponding decrease in acres planted across the region over the past 10 yr (figure 1). At 600 seedlings ac^{-1}, it could be inferred that approximately 424,000 fewer acres were replanted across the region in 2006 than were planted in 1997.

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Table 13. Seedling production (×1000) and acres planted as reported to the Forest Service (1996–1998) and Nursery Cooperative Seedling Production Survey (2004–2006) for the Southern United States.

State	Season							
	1996–1997[a]			1997–1998[a]			2004–2005	2005–2006
	Production (×1000)	Acres planted	Seedlings ac^{-1}	Production (×1000)	Acres planted	Seedlings ac^{-1}	Production (×1000)	Production (×1000)
AL	236,625	437,512	541	127,500	309,770	412	174,726	152,365
AR	120,000	109,599	1,095[b]	125,000	113,738	1,100[b]	102,991	112,876
FL	160,000	192,840	830[b]	154,821	188,897	820[b]	58,471	56,199
GA	251,362	396,726	634[b]	357,854	416,280	860[b]	271,519	188,826
LA	67,078	144,083	466	66,282	155,508	426	39,730	34,128
MS	6,220	281,829	22	101,498	371,432	273	111,981	98,144
NC	104,000	113,978	912[b]	85,252	105,827	806[b]	70,166	68,740
OK	41,524	13,870	2,994[b]	7,686	21,142	364	2,513	1,694
SC	99,438	165,761	600	97,962	99,202	988[b]	168,120	164,949
TN	8,079	7,205	1,121[b]	13,000	11,420	1,138[b]	13,091	6,980
TX	125,900	107,813	1,168[b]	106,000	162,617	652[b]	119,772	118,141
VA	48,420	90,961	532	57,137	101,374	564	33,588	42,325
Total	1,268,646	2,062,177	$\bar{x}$ =615[c]	1,299,992	2,057,207	$\bar{x}$ =632[c]	1,166,668	1,045,664

[a] Data from Moulton (1999) and Moulton and Hernandez (1999).

[b] States with a large number of seedlings ac^{-1} would appear to be net seedling exporters, based on the average seedling density of 500 seedlings planted ac^{-1}. States with a small number of seedlings ac^{-1} would appear to be net seedling importers for reforestation needs.

[c] Average number of seedlings planted ac^{-1} across the region = annual production/ac planted.

[d] Acres planted across the region = annual production/600 seedlings ac^{-1}. We believe that 600 seedlings ac^{-1} is high, but we used this figure to be consistent with Forest Service data for 1997 and 1998.

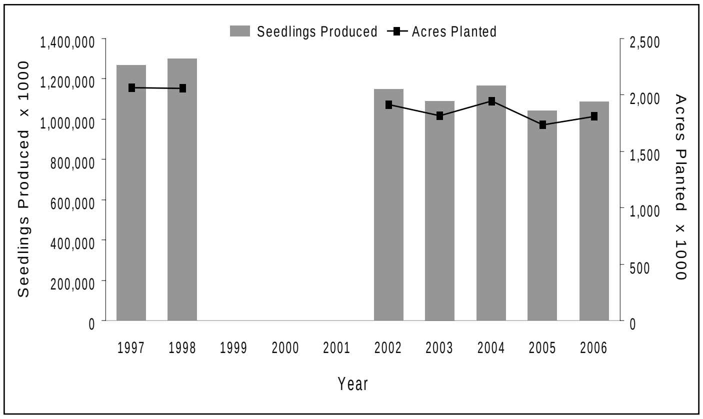

Figure 1. Total hardwood and conifer seedling production and acres planted for the U.S. southern region 1997–2006. Data for 1997 and 1998 are from Moulton (1999) and Moulton and Hernandez (1999). Data for 2002–2006 are from Auburn University Southern Forest Nursery Management Cooperative's regional survey (McNabb and VanderSchaaf 2003; McNabb and Santos 2004; McNabb 2005, 2006). Seedling production information was not collected for 1999–2001. Acres planted for 2002–2006 = (annual production/600 seedlings ac-1). We believe that 600 seedlings ac-1 is high, but this figure is consistent with Forest Service data for 1997 and 1998.

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Use of Pesticides in Bareroot Hardwood Seedbeds in the Southern United States

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Abstract

Pesticides are used in bareroot hardwood nurseries to avoid losses and to reduce the cost of seedling production. In 2001, the Auburn University Southern Forest Nursery Management Cooperative sent a questionnaire to all its nursery members to assess the level of pesticide use. Fifteen questionnaires were returned from nurseries that were growing hardwoods. One objective of the survey was to determine the relative importance and use rates of pesticides in hardwood nurseries. Results indicate that, in growing a million hardwood seedlings, nursery managers use about 944 kg of fumigants, 13 kg of herbicides, 3 kg of insecticides, and 0.6 kg of fungicides (weights are expressed in terms of active ingredient). The overall cost of pesticide treatments account for about 3 percent of the crop value. Documenting actual pesticide usage is one way to assess how nursery practices have evolved over time.

Introduction

In 2001, a survey was mailed to 84 forest tree nurseries throughout the Southern United States. Managers from 39 nurseries returned the questionnaires. These managers produced 1.19 billion pine seedlings on 702 ha (about 81 percent of the actual production for the South). Fifteen of the 39 nurseries produced a total of 22.3 million hardwood seedlings, about 46 percent of the 47 million hardwood seedlings (table 1) reported for the South (McNabb and VanderSchaaf 2003). The 22 million hardwood seedlings were produced on 51 ha for an average stocking of 440,000 seedlings per ha.

All of the hardwood managers reported using fumigants, eight regularly used insecticides, seven reported regular use of fungicides, and all used herbicides. An earlier report described some of the chemicals used in pine nurseries (South and Zwolinski 1996). This report documents pesticides used during the production of bareroot hardwood seedlings in 2001.

Fumigation

Effective soil fumigation is a cornerstone of an Integrated Pest Management (IPM) plan for the production of hardwoods in bareroot tree nurseries. Several nurserymen indicated fumigation as more important in hardwood than in pine seedbeds because of less effective registered herbicides and the higher value of hardwood stock. Several managers reported growing hardwoods only on first-year fumigated fields (as opposed to growing two crops of hardwoods after 1 yr of fumigation). Fumigation was justified by reducing risks associated with injury from nematodes, white grubs, competition from weeds, and soilborne pathogenic fungi.

Table 1. A partial list of hardwoods produced in forest tree nurseries in 2002–2003 (adapted from McNabb and VanderSchaaf 2003).

Common name	Genus	Species	Seedlings produced
Oak	*Quercus*	various	27,325,800
Green ash	*Fraxinus*	*pennsylvanica*	2,621,500
Yellow poplar	*Liriodendron*	*tulipifera*	1,282,800
Dogwood	*Cornus*	*florida*	892,900
Pecan	*Carya*	*illinoensis*	892,000
Sycamore	*Platanus*	*occidentalis*	782,000
Sweetgum	*Liquidambar*	*styraciflua*	638,200
Black walnut	*Juglans*	*nigra*	508,000
Cottonwood	*Populus*	*deltoides*	320,000
Others	—	—	11,849,000
Total			47,112,200

Fumigation rates varied from 390 to 450 kg ai ha^{-1} of methyl bromide and chloropicrin, with chloropicrin making up 33 percent (8 nurseries), 10 percent (1 nursery) or 2 percent (6 nurseries) of the formulation.

Insecticides

Insect pests can be placed into a few categories based on where they live and how they feed. Root-feeding insects are typically killed by effective fumigation. Important airborne insects occurring in most bareroot hardwood nurseries can be divided into two groups: foliage feeders and sapsucking insects.

Insecticides fall under three categories: systemic, stomach, and contact poisons. Systemic poisons (e.g., dimethoate) are applied to the seedling or soil and move into the plant cells. Sapsucking insects such as bugs, aphids, and scales consume large quantities of plant sap. Their feeding habits greatly increase the exposure of these insects to most systemic insecticides. Therefore, systemic insecticides can be effective at concentrations that are not generally toxic to foliage-feeding insects. In contrast, nonsystemic insecticides (stomach and contact poisons such as bifenthrin, chlorpyrifos, diazinon and esfenvalerate) have little effect on sapsucking insects because the insects don't consume foliage on which the insecticide has been placed.

Foliage-feeding insects are typically controlled by stomach poisons on the leaf surface, systemic insecticides, and, to a lesser extent, contact poisons sprayed directly on the pest. For example, stomach poisons such as esfenvalerate and chlorpyrifos have residual activity against grasshoppers (suborder Caelifera) and the larvae (caterpillars) of Lepidoptera. Therefore, when selecting an insecticide to control these foliage-feeding insects, either a stomach poison applied to the foliage or a systemic pesticide would be the preferred choice (assuming the cost and human hazards are similar).

Eight of the managers who produced hardwood seedlings either scheduled prophylactic applications of insecticides or expected to spot-treat part of the seedling crop after scouting for insect damage. Although the tarnished plant bug [*Lygus lineolaris* (Palisot de Beauvois)] is occasionally observed as a problem in hardwood seedbeds, the only sapsucking insects mentioned in the survey were pests from the family Phylloxeridae and aphids (both of which were reported on oak). These insects tend to be sessile (don't move around once they are established) and would be controlled by either systemic or contact insecticides.

Organophosphates. At six nurseries, a total of 59.5 kg of active ingredient (ai) of organophosphates was used to treat hardwood insect problems. One nursery applied 0.5 kg ai of malathion (a contact insecticide); the remaining 59 kg was evenly distributed among chlorpyrifos, diazinon, and dimethoate (table 2). Although the effective application rates are higher for organophosphates than for the fourth-generation pyrethroids such as esfenvalerate (see below), the organophosphates work better in the soil than most pyrethroids.

Chlorpyrifos was used by four hardwood managers, who treated at an average rate of 1 kg ai ha^{-1}. Much of the chlorpyrifos was reportedly used to control late-season foliage feeders such as grasshoppers. When insects are found in certain cover crops, the agricultural product (Lorsban®) might be appropriate.

Dimethoate was used at one hardwood nursery that, by virtue of four applications to all its hardwood seedbeds, made dimethoate the most used insecticide in terms of area treated. The target pests were foliage and sapfeeders; the use rate was 0.56 kg ai ha^{-1}. As a rule, systemic insecticides like dimethoate are most effective against sucking insects and mites and may not be effective against foliage feeders. The occasional use of dimethoate in an insect control program should reduce the chance that pyrethroid resistance will develop.

More diazinon was used in hardwood seedbeds in 2001 than any other insecticide (table 2). It was used for basically the same foliage-feeding insects as chlorpyrifos. Diazinon has been used since 1952, and there is considerable efficacy data for soil and foliage insects (especially for house and garden uses); however, there are few published data for nursery hardwood pests. Although diazinon is not a "restricted use pesticide," most managers prefer to apply other insecticides for managing destructive insects.

Synthetic Pyrethroids. The synthetic pyrethroids are chemically related to a natural insecticide (pyrethrum) that was originally obtained from chrysanthemums. Esfenvalerate is a fourth-generation pyrethroid that is the α-isomer of the third-generation fenvalerate, which it replaced. The original botanical extracts of pyrethrum were not stable in sunlight and rather expensive, but the synthetic pyethroids are more stable in light and are active for up to 10 d. Although earlier generation synthetic pyrethroids were effective at lower rates (112–224 g ai ha^{-1}) than the organophosphates, the fourth-generation products are effective at one-tenth those rates (11–22 g ai ha^{-1}).

Table 2. A partial list of pesticides used at 15 hardwood nurseries and the total amount used on 51 ha in 2001.

Common name	Original trade name	Additional trade names	Total used in 2001 (kg ai)	Restricted use pesticide	Restricted entry interval (h)
Insecticides					
bifenthrin	Talstar	Bifenthrin	2.3	Yes	12
chlorpyrifos	Dursban	Chlorpyrifos, Lorsban	20.5	Yes	24
diazinon	Diazinon	various	24.5	Yes	12
dimethoate	Cygon	Dimethoate	14.1	Yes	48
esfenvalerate	Asana	—	1.8	Yes	12
malathion	Malathion	various	0.5	No	12
		Total	63.7		
Fungicides					
chlorothalonil	Bravo	Chlorothalonil	8.6	No	12
propiconazole	Banner	Propiconazole	0.027	No	24
thiram	Thiram	Gustafson 42-S	1.5	No	24
triadimefon	Bayleton	various	13.3	No	12
		Total	23.4		
Herbicides					
clopyralid	Lontrel	Stinger	2.3	No	12
fluazifop-butyl	Fusilade	—	9.5	No	12
glyphosate	Roundup	Various	51.3	No	4
oryzalin	Surflan		0.2	No	24
oxyfluorfen	Goal	Galigan	10.4	No	24
napropamide	Devrinol		148	No	12
prodiamine	Barricade	Endurance; Factor	33.6	No	12
sethoxydim	Poast	Sethoxydim	28	No	12
trifluralin	Treflan	Trifluralin	7.7	No	12
		Total	291		
Fumigants					
chloropicrin	Various	—	3,603	Yes	0.1 ppm*
methyl bromide	Various	—	17,452	Yes	5.0 ppm*

* May enter when concentration in the air is at or below this level.

Esfenvalerate was used at four hardwood nurseries to treat 54 ha, counting reapplications. The average rate per application was 34 g ai ha^{-1}. More hardwood seedbeds were treated with esfenvalerate than with chlorpyrifos in 2001. Bifenthrin was used at one hardwood nursery. Bifenthrin is rare among pyrethroids in having "significant" soil activity and is effective for control of the imported fire ant (*Solenopsis invicta*). It was used for soil insects and was normally applied at rates from 6 to 56 g ai ha^{-1}. It may be that bifenthrin will be used in the future as a soil treatment for many insect problems, including fire ants and termites (order Isoptera).

Dividing the total amount of insecticides applied (63.7 kg) by 22.3 million seedlings indicates that 2.9 kg of insecticides were applied to a million seedlings. In 1996, nursery managers in Finland applied about 1.2 kg of insecticides per million bareroot seedlings (Juntunen 2001).

Fungicides

Several fungicides are used to prevent or control diseases of hardwoods. Seven managers applied fungicides to their hardwood beds; the total amount applied was minimal (13.6 kg ai). Even doubling this amount to account for hardwood production reported in the production survey projects an "insignificant" market for fungicides.

Triadimefon was the most frequently used fungicide reported for hardwoods; it was used primarily to control powdery mildew on white oaks (*Quercus* spp.). It was used at four hardwood nurseries, which together used 3.2 kg ai. The average use rate in hardwoods was 302 g ai ha^{-1}.

Chlorothalonil was the most used fungicide by weight. It was used at four hardwood nurseries for various foliage diseases. The average reported use rate was 840 g ai ha^{-1}. Chlorothalonil is one of the most popular fungicides in general agricultural use. It is generally effective against most foliar pathogens that cause leaf spots, blights, necrosis, etc., in many crops.

Thiram was used by one hardwood nursery to treat acorns before sowing at a rate of 0.8 kg ai 100 kg^{-1} of acorns. In addition to being a fungicide, thiram may also be effective as a bird and mammal repellent (Abbott 1958; Holms and others 1988).

Propiconazole was used at one hardwood nursery for control of powdery mildew on white oaks. Its activity is similar to that of triadimefon, and its use for powdery mildew (numerous fungi fall under this general description) seems a matter of preference. Only 0.2 ha of oaks were treated in 2001.

Dividing the total amount of fungicides applied (13.3 kg) by 22.3 million results in 0.6 kg of fungicides per million seedlings. In Finland this value was 5.6 kg per million bareroot seedlings (Juntunen 2001).

Herbicides

Herbicides can be grouped into selective (not generally harmful to hardwood seedlings) or nonselective (should not contact bark and foliage). If an herbicide is applied to emerged hardwoods and kills both weeds and the hardwoods, it is nonselective. Glyphosate is typically a nonselective herbicide, but sethoxydim (which kills only grasses) is selective in hardwood seedbeds. These designations are useful when we know the specific crop/weed system involved.

The terms preemergence or postemergence are also used to describe when the herbicide is applied to the crop or weed. For example, herbicides such as napropamide kill germinating weeds before they emerge through the soil surface. This herbicide is applied after emergence of the hardwood crop but before emergence of the weed. Since the weeds have not yet emerged, napropamide is classified as a preemergence herbicide. This designation occasionally causes confusion, however, especially when the preemergence herbicide is applied after emergence of the crop.

Nonselective Herbicides. Glyphosate is a foliar-applied, nonselective herbicide with no soil activity. It inhibits an enzyme found only in plants and so may pose little risk for other organisms such as mammals, birds, fish, or insects. Glyphosate is bound tightly to soil particles and is unlikely to move offsite. The relatively slow absorption of glyphosate into foliage causes rain within a couple of hours of application to reduce effectiveness. There is no legal limit to the number of applications that may be applied in a year. Glyphosate may be applied between drills with shielded sprayers. Some genetically modified cover crops have a glyphosate-resistant gene that some managers use as part of an IPM program to reduce nutsedge (*Cyperus* spp.) in cover crops. Use of glyphosate may increase in both cover-crop and noncrop areas if the production of methyl bromide ceases. Five nurseries used glyphosate "as needed" to control troublesome weeds, and some used scheduled, shielded applicators; average use rate was 2.6 kg ai ha^{-1}.

Selective Herbicides. Sethoxydim was used at more hardwood nurseries than any other herbicide. Sethoxydim is a postemergence herbicide that is effective against annual and perennial grasses. It is quickly absorbed by foliage and is rain-fast after 1 h. Although there are limits to the amount that can be applied to certain agricultural crops, these rates are based on avoiding undue stress to the crop. The average reported application rate was 0.3 kg ai ha^{-1}, with rates ranging from 0.22 to 0.45 kg ai ha^{-1} per application, depending upon the size of the grasses. Most nurseries applied two treatments; a few applied three.

Napropamide was applied at six hardwood nurseries (average, 2.6 kg ai ha^{-1}), which made it the most used herbicide. Napropamide was applied to control both grasses and broadleaf annual weeds. Its selectivity is based mainly on the timing of herbicide application (i.e., after seedling establishment but before germination of weed seed). In some cases, napropamide can reduce germination of chestnut oak [*Quercus prinus* (L.)] (Reeder and others 1991). For this reason, it is commonly applied over established seedlings and after true leaves have emerged (South 1986). It does not have any contact activity, so it is best to apply napropamide to a weed-free soil.

Fluazifop-butyl was registered for nurseries in the 1980's. The target weeds and application methods are very similar to sethoxydim. Both are selective, foliar-absorbed, systemic herbicides that are effective against grasses but have no effect on dicots or sedges. It is effective against crabgrass (*Digitaria* spp.) and bermudagrass [*Cynodon dactylon* (L.) Pers.]. It can be applied to most broadleaf crops with little risk of injury and is most effective applied to weeds in the two- to four-leaf stage. There is some soil activity at higher rates, and sensitive grasses may be affected for up to 4 mo after application. The active ingredient breaks down rapidly in the soil. The single application limit is 0.2 kg ai ha^{-1}, but the annual amount is not limited. This herbicide is toxic to fish and so should not be used too close to ponds, creeks, or rivers.

Fluazifop-butyl is effective at rates as low as 112 g ai ha^{-1}; the average use rate was 336 g ai ha^{-1} (5 of 8 nurseries used less than 224 g ai ha^{-1} per application). Most nurseries made about two applications per year. Although only 9.5 kg ai were used in 2001, about as many ha were treated with fluazifop-butyl as with any other herbicide.

Oxyflurofen is labeled for use on field-grown deciduous trees. It was used primarily as a preemergence herbicide (applied just after sowing) on large-seeded hardwoods at five nurseries. Newly emerged seedlings can be injured (South 1984). A granular formulation (containing 2 percent oxyflurofen and 1 percent oryzalin) can be applied to emerged hardwoods without significant injury (Reeder and others 1991; 1994). Five nurseries used oxyflurofen at an average rate of 448 g ai ha^{-1}, and one manager used 0.4 kg ai of the granular formulation. This herbicide is active against a broad range of annual broadleafed weeds and grasses. Granular formulations that contain oxyfluorfen will cause less injury to foliage than an emulsifiable concentrate formulation. At some nurseries, the liquid formulation is also applied as a directed spray to established field-grown hardwoods (South 2004). Oxyflurofen binds to soil particles, forming a chemical barrier to weed emergence that can be broken by mechanically disturbing the soil surface. Large-seeded hardwoods can usually penetrate this soil barrier without much damage. The label restricts application to not more than 2.2 kg ai ha^{-1} yr^{-1}.

Clopyralid was used at one hardwood nursery. This herbicide is active against troublesome legumes such as javabean [*Senna obtusifolia* (L.) Irwin and Barneby], which has tolerance to methyl bromide fumigation. Clopyralid is a selective postemergence herbicide that is absorbed by both foliage and roots (South 2000).

Prodiamine is a selective preemergence herbicide that control annual grasses and some broadleaf weeds (South 1992). Weeds are not controlled after they have emerged, and weed control is best when application is followed by at least 1.25 cm of irrigation. There is no limit on the annual application of this herbicide except as made necessary by crop sensitivity (Altland 2005). Prodiamine was used at three hardwood nurseries, but one nursery accounted for 72 percent of the total amount applied. The typical application rate was 448 g ai ha^{-1}.

Trifluralin is typically incorporated into the soil before sowing agronomic crops, but in hardwood nurseries it is often applied and watered in just after sowing. This reduces the likelihood of reducing root growth. Irrigation is applied immediately after treatment to reduce volatilization. Small-seeded species are sensitive to trifluralin; therefore, managers should not apply this herbicide to small-seeded hardwoods, such as sycamore. Two nurseries applied trifluralin as a preemergence herbicide at 1.1 kg ai ha^{-1}, and one applied this rate after germination was complete.

After dividing the total amount of herbicides applied (291 kg) by 22.3 million seedlings, the amount used is approximately 13 kg per million seedlings. For the southern pines, this value is about 2.5 kg per million seedlings (South and Zwolinski 1996). In contrast, in Finland the ratio was 5.6 kg per million bareroot seedlings (Juntunen 2001). In bareroot nurseries in the Southern United States, managers applied, on average, about 2.0, 2.9, and 1.7 kg a.i. ha^{-1} $crop^{-1}$ of herbicides, fungicides and insecticides, respectively (South and Zwolinski 1996).

Economics

Some nursery managers base their pest management decisions on securing economic profits and on maintaining good reputations for producing disease-free stock. The main economic justifications for using pesticides include keeping seed efficiency high (South 1987) and production costs low. Examination of a hardwood nursery budget might reveal that pesticide treatments amount to less than 4 percent of the retail value of the crop (table 3). Currently, fumigation with methyl bromide and chloropicrin before sowing accounts for a large portion of these costs.

It is interesting to note that pest control costs in hardwood seedbeds represent a lower overall percentage of retail seedling sales than such costs in pine seedbeds. This percentage might be 3 percent for hardwoods (table 3) but 6–7 percent in pine seedbeds (South and Enebak 2006).

When nursery pests are controlled using effective chemicals, the cost of producing a thousand hardwood seedlings can be less than $300 per thousand, while the cost of

Table 3. Approximate costs of pest management in hardwood nurseries based on average use rates reported in 2001. Value calculations assume 440,000 seedlings ha^{-1} and a price of 30 cents per seedling.

Pest group	Active ingredient (kg/ha^{-1})	Cost ($) per		Percentage of total crop value
		ha	thousand seedlings	
Foliage and stem fungi	0.3	44	0.10	0.03
Birds and mice	0	0	0	0
Annual weeds	2	190	0.43	0.14
Insects	1.25	100	0.23	0.08
Nematodes, soil fungi, and sedges	400	3,800	8.64	2.9
Total		4,134	9.40	3.1

pesticide treatments might be $10 per thousand (table 3). The retail price for bareroot oak seedlings in the Southern United States may vary from $200 to $400 per thousand.

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Disclaimer

The mention of commercial products is solely for the information of the reader. Endorsement is not intended.

Acknowledgments

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More Library References for Readers of Tree Planters' Notes

Robin Rose

Managing Editor, Tree Planters' Notes, *and Professor of Forest Regeneration, Oregon State University, Corvallis, OR*

It was such a pleasant surprise to get a response from Frank Bonner, Forest Service (ret.). He wrote as follows:

I just received my copy of the latest TPN, and the list of reference books you put in was a pleasant surprise. Something like this never shows up in other places (or, at least, that I ever saw). Now I will take you up on your invitation and list a few more books that have some value in this field.

A Guide to Bottomland Hardwood Restoration. J.A. Allen and others. 2001 (revised 2004). Washington, DC: U.S. Geological Survey, Biological Resources Division Information and Technology Report USGS/BRD/ITR-2000-0011; Asheville, NC: Forest Service, Southern Research Station, General Technical Report SRS-40. 132 p.
The work provides a good overview of regeneration in the bottomlands of the South.

Forest Regeneration Manual. M. Duryea and P. Dougherty, eds. 1991.Dordrecht: Kluwer Academic Publishers. 433 p.
This is another general manual on the topic, though maybe a little outdated by now.

Wildland Shrubs of the United States and its Territories: Thamnic Descriptions: Vol. 1. John Francis, ed. 2004. Gen. Tech. Rep. IITF-GTR-26. San Juan, PR: Forest Service, International Institute of Tropical Forestry, and Ft. Collins, CO: Forest Service, Rocky Mountain Research Station. 830 p.
This publication would be very valuable in making the choice of which shrub species would be best in certain situations. There is solid information on flowering and seed production, but not much on how to collect, clean, and treat the seeds. Still, its value lies in the fact that it covers shrubs like no other book that I know.

Tree and Shrub Seed Handbook. A.G. Gordon, P. Gosling, and B.S.P. Wang, eds. 1991. Zurich: International Seed Testing Association. 190 p.

Also a little dated, it still has value regarding official seed testing procedures. While newer testing procedures are in place for many species, the basics presented in this manual are worthwhile.

Seed Handling Guidebook. David Kototelo and others. 2001. Victoria, BC: British Columbia Ministry of Forests. 106 p.
This is a very good practical guide for handling tree seeds in Canada. The color photographs add a lot and make you wish that all of our technical books had the same.

Guide to Handling of Tropical and Subtropical Forest Seed. Lars Schmidt, 2000. Humlebaek: Danida Forest Seed Centre. 510 p.
Anyone who has worked overseas knows how talented the staff of the Danida Center are. They have good expertise in tropical/subtropical forest regeneration in all corners of the globe. This book is done in a format similar to what we use in Part 1 of our Forest Service Woody Plant Seed Manual. *It is really good.*

Database of Tropical Tree Seed Research. P.B. Thompsett and R. Kemp., compils. 1996. Ardlingly, West Sussex, UK: Royal Botanical Gardens, Kew, Wakehurst Place. 263 p.
This is another good tropical/subtropical tree seed manual that covers much of the material found in the previous book, but arranged by species. It has good information from a really good group of seed researchers at Wakehurst Place.

It always amazes me to remember that when I started seed research in the early 60s, we had little more that the first Woody Plant Seed Manual *and Phil Wakeley's book on pines. The next generation will do it all with CDs and the Internet, but books will always have a place. By the way, the new* WPSM *revision went to press early in July, and it will be available on CD also.*

Dr. Charles Davey, North Carolina State University (ret.) also sent a nice reminder that there is a newer edition of Mineral Nutrition of Higher Plants. Here it is:

Mineral Nutrition of Higher Plants. H. Marschner. 1995. 2nd ed. Academic Press: San Diego. 889 pages.

By all means, offer up any further books you would like to share with colleagues in the nursery and reforestation community. It may seem silly to suggest a book that is out of print, but all too often it is these gems that contain some fascinating insights.