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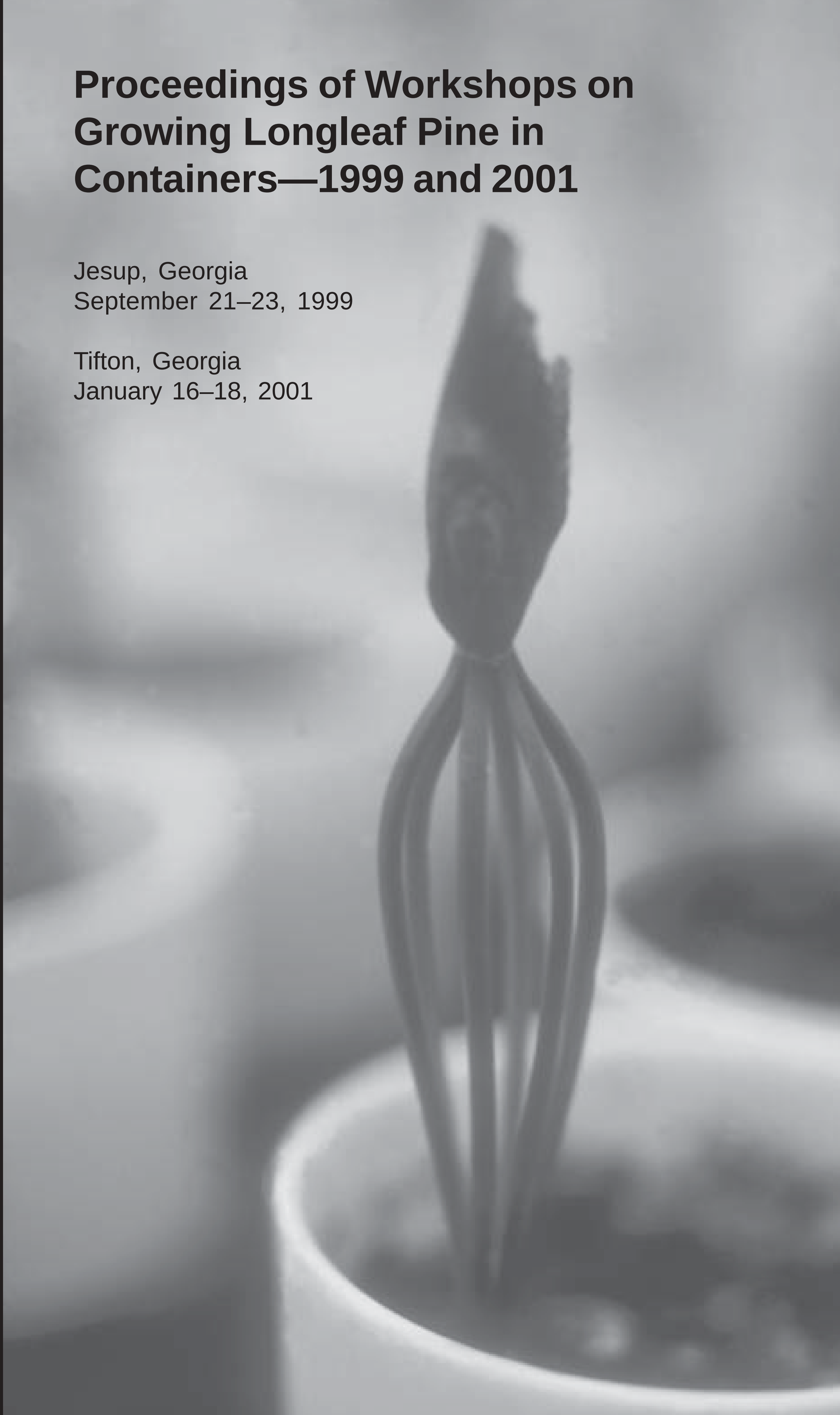
Proceedings of Workshops on Growing Longleaf Pine in Containers—1999 and 2001

Jesup, Georgia
September 21–23, 1999

Tifton, Georgia
January 16–18, 2001



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Proceedings of Workshops on Growing Longleaf Pine in Containers—1999 and 2001

Edited by
J.P. Barnett, R.K. Dumroese, and D.J. Moorhead

Jesup, Georgia
September 21–23, 1999

Tifton, Georgia
January 16–18, 2001

Hosted by
Longleaf Alliance
Georgia Cooperative Extension Service
USDA Forest Service, State and Private Forestry
USDA Forest Service, Southern Research Station

PREFACE

These proceedings consist of a collection of presentations made at the first Longleaf Pine Container Production Workshop at Jesup, GA, and a second meeting about 18 months later at Tifton, GA. The papers included describe and discuss the current knowledge about growing longleaf pine in containers for reforestation in the South. Recommendations are made using the best information available at the time and are, therefore, subject to revision as more knowledge becomes available.

Many individuals and organizations deserve credit for the success of these meetings. The speakers did an outstanding job with their assigned topic: we are especially grateful for the presentations from the nursery managers who shared their trials in developing container production facilities.

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THE LONGLEAF ALLIANCE: A REGIONAL LONGLEAF PINE RECOVERY EFFORT

Dean Gjerstad and Rhett Johnson[1]

Longleaf pine was once the dominate forest over nearly 70 percent of Alabama, ranging from just south of the Tennessee Valley to the Gulf Coast. Today longleaf represents less than 3 percent of Alabama's forest acreage. However, a dramatic recovery of this most important southern ecosystem is underway with interest and support at an all time high among landowners, agencies, and conservation groups.

Longleaf has many attributes desirable to landowners. From a timber point of view, longleaf pine is superior to other southern pines in the production of high value wood products. Its growth form, with typically high form classes and straight boles, results in the production of a high percentage of poles, pilings and high quality logs. Its wood is denser and heavier than that of other pines, an important factor when most wood products are sold on a weight basis today. Longleaf is resistant to many diseases, insects, and other damaging agents common to other southern pines, reducing investment risk. It is seldom damaged by fusiform rust, a serious pathogen in slash and loblolly pine; resists attack by southern pine beetles; and is very tolerant of fire throughout most of its life cycle. Its open stands are conducive to a diverse ground cover plant community providing habitat to a multitude of insects, birds and animals.

With so many attributes, why then has the longleaf forest been systematically harvested and then regenerated to other species? The reasons for its precipitous decline are many and are rooted in the history of the South.

For much of the past five millennia longleaf pine was the dominant tree species on the southern uplands ranging from southeast Virginia down the Atlantic Coast and across the Gulf Coast to East Texas. Landscape-scale fires that swept across most sites every 3–5 years maintained this prehistoric longleaf forest, eliminating other less fire tolerant species. These frequent fires not only resulted in longleaf dominating the upland sites but also produced fire dependent animal and ground cover plant communities considered to be among the most biodiverse of all forest systems.

European explorers described these forests as open, park-like stands with grassy ground cover containing little or no hardwood. Early lumbermen prized longleaf in the production of high value wood products because of its straightness and superior wood properties as compared to other southern pines. The initial extraction of longleaf was slow because only timber adjacent to waterways was accessible for harvesting until the development of steam power. Harvesting of the interior uplands peaked in the early 20th century when railroad logging was able to reach the remaining large tracts. When much of the longleaf timber was depleted in the 1920s, mills closed, lumbermen moved on, and few were concerned with regenerating the southern forest when vast tracts of virgin timber lay waiting in the West.

The human influence on the longleaf forest was exacerbated by the fire prevention effort instituted during the first half of the 20th century led by the familiar Smoky Bear. This campaign was designed to stamp out this "destructive" force at all costs. Fire prevention allowed many fire intolerant hardwood and herbaceous species to invade and dominate sites once home to various longleaf ecosystems.

The development of the pulp and paper industry during the 1950s and 1960s began the South's most significant economic revival since the Civil War. Unfortunately for the longleaf ecosystem, the emphasis of this industry was—and is—on wood fiber production. Although longleaf growth rates are competitive with those of other southern pine species on most sites over periods of 30 years or more, the best return on forest investment for companies whose product requires only fiber comes from highly productive short rotation plantations, a kind of silviculture for which longleaf is not well suited.

The major hindrance to longleaf establishment in the minds of many is that longleaf is more difficult to regenerate than loblolly or slash pine. Natural regeneration efforts can be hampered by longleaf's sporadic seed production. Seedling planting must be done to exact specifications because the grass stage seedling has no stem. Weedy competition can retard growth, resulting in seedlings remaining in the grass stage for several years. Fortunately, through current technology, these regeneration problems have been, for the most part, overcome, enabling landowners to regularly and successfully establish vigorously growing longleaf stands.

Although fast growing species like loblolly and slash pine are ideal for the pulp and paper industry, many nonindustrial private forest landowners prefer longleaf pine forests for their valuable timber and associated ecosystem, one that is both aesthetically pleasing and conducive to a diverse plant and animal community. Unfortunately many of these landowners have been unable to readily obtain information and advice

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on longleaf management. The Longleaf Alliance was established in 1996 with the express purpose of coordinating efforts to restore longleaf and its accompanying ecosystem on lands where they are compatible with the objectives of the landowner. This initiative resulted from the recognition that interest in the longleaf ecosystem and the tree itself was growing rapidly. Ecologists, foresters, wildlife biologists, landowners and land managers were searching for information or for an outlet to distribute what they had learned. A growing body of anecdotal information, personal experience, and scientific data was being passed on fitfully and many publics were not being reached. The Longleaf Alliance was formed in an attempt to serve as a clearinghouse for information on longleaf and longleaf forests for the general public.

The Longleaf Alliance is based at Auburn University's Solon Dixon Forestry Education Center in southern Alabama in the heart of the largest longleaf concentration left in the country. It is a nonprofit collaborative effort incorporating a broad community of similar interests in the longleaf forest system. Its structure is simple, its goals direct—the establishment of a functional longleaf forest ecosystem to the extent feasible in today's southern forest environment.

Recognizing and emphasizing the importance of both the economic and ecological value of the longleaf forest broadens the appeal of the Alliance and gives it credibility with both the scientific and private communities. Members include researchers, outreach providers, landowners and managers, tree nurseries, state and federal natural-resource agencies, forestry and wildlife consultants, forest industries, and forestry service providers.

Because the vast majority of forestland acreage in the Southeast is privately owned, the Alliance has directed significant effort to the management and re-establishment of longleaf forests on private lands. This has been done by conducting numerous workshops focused on establishment and management techniques, responding to numerous daily specific inquiries and producing timely publications pertinent to longleaf issues. The effort and the organization are regional in scope, and the Alliance presently has nearly 700 members from every state in the longleaf region.

As a benefit to members, the Alliance maintains and constantly updates databases on current longleaf related research, longleaf seedling nurseries, forestry and wildlife consultants with longleaf expertise, and pertinent research and demonstration sites. The Alliance has held two regional meetings, with each attracting large enthusiastic audiences. The first was held in Mobile, Alabama in 1996 and was attended by over 250 longleaf fans and the second, held in Charleston in November of 1998, attracted 400 attendees. Numerous publications including conference proceedings, a landowner's guide to management of longleaf forests, research notes, newsletters and other pertinent resources are available at a nominal cost.

The Longleaf Alliance is funded through donations, memberships, and grants. Further information on the Alliance is available by writing The Longleaf Alliance, RR 7 Box 131, Andalusia, Alabama 36420, telephone 334-222-7779, fax 334-222-7779, and email addresses dxnctr.alaweb.com, gjerstad@forestry.auburn.edu, or hainds@alaweb.com.

LONGLEAF SEEDLING TRENDS

Mark J. Hainds[1]

Demand for longleaf pine (*Pinus palustris* Mill.) seedlings continues to increase throughout the Southeast. Overall production of longleaf pine seedlings has increased annually for at least the last 3 years (51 percent increase over the past 3 years), while demand for seedlings has continued to exceed the supply. There are several reasons for the increased interest in longleaf pine.

Longleaf pine has long been recognized as the South's finest pine tree. In general, longleaf produces the best quality sawtimber, the greatest percentage of poles, the highest specific gravity per unit volume, and the best quality pine straw. Besides its outstanding physical characteristics, longleaf is also more resistant to insect damage, fusiform rust, and wind-throw, wind-breakage, and fire damage than are loblolly or slash pine. With these outstanding characteristics, why have forest industry and most private landowners converted their land to loblolly or slash pine? The answers can be found in the seedling characteristics and early growth of these three species.

Longleaf seedlings have a "grass" stage during which it has no stem and closely resembles a clump of grass. Loblolly and slash pine, on the other hand, start stem growth immediately after germination. Because loblolly and slash pine seedlings have well-developed stems at planting time, both are easier to plant. Planting depth is critical with longleaf pine. Loblolly and slash pine seedlings have several inches of vertical leeway in which they can be planted and survive. Longleaf has a narrow window (approximately 0.5 to 0.75 in.) in which it can be correctly planted.

Bareroot longleaf pine seedlings are also much less tolerant of abuse than are loblolly or slash pine seedlings. Bareroot longleaf pine seedlings do not ship or store as well as do loblolly or slash. Bareroot longleaf also tend to have longer lateral roots, which make them harder to plant than the other southern pines. The difficulties associated with artificial regeneration of longleaf pine are major reasons why our forests were converted from longleaf to other southern pines.

Another important factor in the decline of longleaf has been the shift by forest industry to short-term volume and fiber production. On most sites, loblolly and slash will produce more volume in short pulpwood rotations. Exceptions to this rule are excessively drained soils such as sand ridges, where longleaf produces as much or more volume in shorter rotations. When rotations are extended for sawtimber and poles, longleaf compares very favorably with loblolly and slash on most soils in its natural range from Virginia to Texas.

Knowing that longleaf is more difficult to plant and does not grow as fast initially, why are people planting more longleaf every year? Again, several factors come into play. Undoubtedly, the advent of container-grown seedlings has been one of the most important factors.

Container-grown longleaf are grown in blocks or cells that produce a seedling where the entire root system is enclosed in a "plug." Good quality container-grown longleaf are hardier seedlings than even bareroot loblolly or slash. This has been well demonstrated on the Solon Dixon Forestry Education Center in lower Alabama, surrounding industrial forestland, and across much of the Southeast where recent spring droughts have caused poor survival and planting failures for bareroot loblolly, slash, and longleaf pine. However, despite 7 to 8 weeks of drought, plantings of container-grown longleaf have yielded 80 to 90 percent survival on several sites.

Container-grown longleaf are more compact than bareroot longleaf, making the plugs easier and faster to plant. Today's hand-planting crews are, on average, more familiar with and comfortable planting container-grown longleaf pine. One large tree-planting contractor even offers guaranteed survival rates when hand-planting longleaf pine seedlings. Longleaf planting success rates have never been better and are increasing every year as planting crews gain experience. In fact, experienced crews planting containerized longleaf can expect similar or higher survival rates as those achieved with bareroot loblolly and slash pine.

Additionally, many landowners are placing other objectives ahead of volume production. One value associated with longleaf pine is the relative security of the investment. Some landowners are replanting slash pine lost to wildfires in Florida with longleaf. Other landowners are replanting stands of loblolly lost to southern pine beetle with longleaf. Still others landowners are converting stagnated stands of slash or loblolly on sand ridges back to longleaf that once dominated these sites. While longleaf is not immune to southern pine beetle, fire, or fusiform rust, a landowner has considerably lower risk associated with longleaf.

Demand for longleaf pine seedlings reflects the increased interest in longleaf pine. South wide, container-grown longleaf production was estimated at 31.1 million seedlings in 1996. Production increased approximately 12 percent in 1997 to 34.9 million. Production increased again in 1998 by 13 percent to 39.6 million. In 1999, it is estimated that production will increase a whopping 36 percent to 54.1

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million seedlings! Bareroot production for 1999 is estimated at 26.5 million for an overall production of 80.6 million longleaf seedlings annually.

Another factor affecting demand and production of longleaf pine seedlings is the Conservation Reserve Program (CRP). Landowners signed up over 100,000 acres of cropland to be planted to longleaf pine in the next 2 years, with nearly 75 percent of this acreage located in Georgia. With the increased demand that is provided by the CRP, as well as a greater demand to regenerate cutover tracts, it may take several years before longleaf seedling production can meet demand.

Unfortunately, a bottleneck in longleaf restoration may arise in the year 2000. Seed companies purchased virtually all-available longleaf seeds in 1999, with little available for sale. Even worse, it appears that cone and seed production will be low across most of the Southeast this year. Unless seed becomes available, overall production of longleaf pine seedlings will probably decrease in 2000.

In the long term, things are looking up for longleaf pine. The Longleaf Alliance tracks nursery production and produces the “Longleaf Nursery List”. The Alliance has added numerous nurseries to the “Longleaf Nursery List” in the last couple of years. When more seeds become available, production will probably increase dramatically. This spring’s flower production suggests that we may have a bumper cone crop in 2000. The seed companies have indicated that with a good cone crop they will greatly increase their seed collection efforts.

Furthermore, foresters, tree planters, herbicide applicators, and landowners are becoming more familiar with the silvicultural techniques required to successfully regenerate longleaf pine. Many landowners have developed a “spiritual” attachment to this beautiful tree and ecosystem. As landowners see successful established longleaf pine plantations become commonplace, they are becoming more interested in planting longleaf on their property.

Longleaf may also be the most viable economic alternative for many landowners. Data from timber sales in Alabama and Mississippi consistently reflect superior prices paid for longleaf timber. From timber sold off the Solon Dixon Center in 1999, longleaf sawtimber and poles have yielded roughly five to seven times the price per unit volume as compared to loblolly pulpwood. Stands of longleaf sawtimber consistently bring higher prices per thousand board feet than do similarly aged stands of loblolly.

The Longleaf Alliance is a partnership of private landowners, forest industries, State and Federal agencies, conservation groups, researchers, and other enthusiasts interested in managing and restoring longleaf pine forests for their ecological and economic benefits. Membership is approaching 700 individuals and organizations and is growing at a rapid rate. The Longleaf Alliance serves as a clearinghouse for information on regenerating, restoring, and managing longleaf pine; provides networking opportunities for members to connect with other landowners, managers, and researchers with similar interest and problems; and coordinates technical meetings and educational seminars. In addition, the Longleaf Alliance maintains and constantly updates databases of current longleaf related information, seedling nurseries, wildlife and forestry consultants, and pertinent demonstration sites. Numerous publications are available, including conference proceedings, a landowner’s guide to longleaf management, research notes, and newsletters. The Alliance conducts applied research on artificial regeneration, natural regeneration, prescribed fire, herbicides, and site preparation for longleaf establishment.

For more information on longleaf or becoming a member of The Longleaf Alliance phone us at 334-222-7779, fax 334-222-0581, or mail us at: Longleaf Alliance, RR 7 Box 131, Andalusia, AL 36420.

LONGLEAF PINE: WHY PLANT IT? WHY USE CONTAINERS?

James P. Barnett[1]

ABSTRACT—Longleaf pine (*Pinus palustris* Mill.), although widely distributed in the presettlement forests of the southern Coastal Plain, now occupies less that 5 percent of its original range. A highly desirable species, it resists fire, insects, and disease, while producing excellent quality solid-wood products. Longleaf forests also represent an important component of the region's cultural heritage, ecological diversity, timber resources; it provides essential habitat for many animal and plant communities. However, regeneration of the species either by natural methods or by planting of bare-root nursery stock has been difficult. The renewed interest in growing longleaf pine has resulted in evaluation of new approaches to seedling establishment. Using container stock and controlling competition have greatly improved the success of longleaf pine establishment.

INTRODUCTION

Of the southern pines, many consider longleaf pine (*Pinus palustris* Mill.) the most valuable in terms of wood-product quality, aesthetics, and resistance to fire, insects, and disease. Longleaf pine ecosystems once occupied more than 90 million acres of the Lower Coastal Plain of the Southeastern United States from southern Virginia to central Florida and west to eastern Texas (Frost 1993). Heavily harvested in the late 1800s and early 1900s, few longleaf stands survived. Today, less than 4 million acres remain (Kelly and Bechtold 1990). Few seed trees endured these harvests, and much of the area was converted to other species or abandoned to grassland. Natural regeneration is only feasible on a small portion of the area in the longleaf pine type.

Regeneration, both naturally and artificially, is more difficult than for any other southern pine due to the delay in stem elongation (the grass stage) that is a genetic trait of the species. Survival of planted bare-root nursery stock is generally poor, and established seedlings in the grass stage are very sensitive to competition. Using container stock and controlling competition by other vegetation have improved regeneration results. Although the acreage of longleaf pine will never attain historical proportions, future restoration will increase the production of quality wood for humans, the number of species-rich plant communities, and the amount of suitable habitat for wildlife.

THE LONGLEAF PINE ECOSYSTEM

The natural range of the longleaf pine ecosystem covers most of the Atlantic and Gulf Coastal Plains with extensions into the Piedmont and mountains of north Alabama and northwest Georgia. The species occurs on a wide range of sites, from wet, poorly drained flatwoods near the coast to dry, rocky mountain ridges (Boyer 1990). It is a long-lived tree, potentially reaching the age of several hundred years. However, longleaf pine forests are often exposed to catastrophic hazards, such as tropical storms or fire, and to continuing attrition from lightning, which shortens possible rotation ages (Landers and others 1995).

The Nature of the Species

Longleaf pine is a pioneer species that is very shade intolerant. The seedlings evolve through a stemless grass stage. If competition is severe, they may remain in this grass stage for years. The ecosystem is distinguished by open, park-like pine barrens, which are composed of even-aged and multi-aged mosaics of forests, woodlands, and savannas, with a diverse groundcover dominated by bunch grasses and usually free of understory hardwoods and brush (Landers and others 1995). The diversity of understory plants per unit of area places longleaf pine ecosystems among the most species-rich plant communities outside the tropics (Peet and Allard 1993). Although the pine-barrens are known for persistence and diversity, they occur on infertile soils. The ecological persistence of these areas is a product of long-term interactions among climate, fire, and traits of the key plants.

The Role of Fire

Fire was an essential component of the original longleaf pine ecosystems. Longleaf pine and bunch grasses, such as wiregrass and certain bluestems, possess traits that facilitate the ignition and spread of fire during the humid growing seasons (Landers 1991). Frequent fire was largely responsible for the competitive success of longleaf pine and the grasses. These keystone species exhibit pronounced fire tolerance, longevity, and nutrient-water retention that reinforce their dominance and restrict the scale of vegetation change following disturbance. Fires that were ignited by American Indians or by lightning from thunderstorms prevailed over the region. Many of these fires occurred during the growing season and prevented species native to other habitats from encroaching into the pine barrens. The chronic fire regime also maintained the soil structure and nutrient dynamics to which longleaf pine is adapted (McKee 1982).

The Decline of the Longleaf Ecosystem

The depletion of the longleaf ecosystem resulted from its many desirable attributes that caused its exploitation by European settlers (Croker 1979). However, railroad

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harvesting in the late 1800s and early 1900s provided access to and depleted the vast remaining longleaf timberland. Cutting proceeded from the Atlantic States west through the Gulf Coast region as use of the wood intensified. The harvesting of longleaf pine reached a peak in 1907, when an estimated 13 billion board feet were cut (Wahlenburg 1946). The longleaf ecosystem now occupies only a small part (less than 5 percent) of its original area. Reduced acreage of this habitat type has placed at risk at least 191 taxa of vascular plants (Hardin and White 1989, Walker 1993) and key wildlife species such as the red-cockaded woodpecker, gopher tortoise, and southern fox squirrel (Landers and others 1995).

A combination of circumstances limited regeneration of longleaf pine. The completeness of the harvest left little seed source for natural regeneration, and much of the harvested land was cleared for cropland or pasture. Longleaf pine does not successfully invade open land in competition with aggressive pine or grass species. Regeneration sometimes succeeded old-growth when periodic fires provided a seedbed and controlled woody competition and when wild hogs did not reach a density high enough to destroy established seedlings (Landers and others 1995). The disruption of natural fire regimes, resulting in part from forest fire protection policies implemented during the 1920s, allowed invasion of longleaf sites by hardwoods and more aggressive pine species. Longleaf pine and its associated species could not compete under these conditions.

ESTABLISHMENT BY PLANTING CONTAINER STOCK

Artificial regeneration is used to restore longleaf pines on most sites where the species originally grew. Historically, reforestation by planting bare-root stock has been unacceptable. Problems related to severe competing vegetation, delayed stem elongation, and poor storability of bare-root seedlings have hindered success. Within the last decade, the keys to successful establishment have been available: well-prepared, competition-free sites; healthy, top-quality, fresh planting stock; meticulous care of stock from lifting to planting; precision planting; and proper post-planting care (Barnett 1992). To be consistently successful, all five keys must be met. Because land managers are rarely able to control all five factors, successful planting of bare-root stock remains elusive.

Development of Container Technology

Planting of container stock is now accepted as the most successful method of regenerating longleaf pine (Barnett and McGilvray 1997). Numerous studies have demonstrated that under adverse planting conditions, such as poor sites, moisture stress, and out-of-season plantings, container seedlings survive and grow better than bare-root stock (Barnett and McGilvray 1993, South and Barnett 1986). Boyer (1989) found in a 5-year comparison of bare-root and container plantings in Georgia that the container stock averaged 76 percent survival compared to 51 percent for bare-root stock. Improved survival and growth rates are generally attributed to root systems of container seedlings remaining intact during lifting while roots of bare-root seedlings are severely damaged. Comparative studies have shown that internal moisture stress is consistently less in outplanted container seedlings than in bare-root seedlings (Becker and others 1987). Thus, container seedlings experience a significantly shorter period of transplant shock or adjustment than bare-root seedlings. Practical guidelines for producing longleaf pine in containers are currently available (Barnett and McGilvrary 1997).

Importance of Competition Control

Fire is an essential component of the establishment and management of the longleaf pine ecosystem. Long-term studies show that the frequent use of fire hastens initiation of height growth, reduces undesirable competing vegetation, and stimulates growth and development of species that are an essential component of the understory. Fire is also a critical component for achieving and maintaining the biologically diverse understory that is characteristic of the ecosystem.

When the use of fire is restricted by regulations, location, or condition of the site, herbicides can be used to release longleaf seedlings from excessive competition, either before and after planting. Postplanting competition control is important to ensure early initiation of height growth.

CONCLUSIONS

Longleaf pine is a highly desirable species because it produces excellent quality solid-wood products and resists fire, insects, and disease; its understory typically supports a species-rich plant community. The longleaf pine ecosystem also favors key wildlife species such as the red-cockaded woodpecker, gopher tortoise, and southern fox squirrel. Reforestation success for longleaf pine can be improved by planting seedlings produced in containers. Container stock survives better than bare-root stock on typical longleaf pine sites, and the length of time seedlings stay in the grass stage is reduced. However, using container stock does not eliminate the critical need for controlling competition during the first growing season to ensure that seedlings begin height growth during the second year after planting. By using container stock and controlling competitive vegetation, land managers are more likely to achieve successful reforestation of longleaf pine—a culturally, ecologically, and economically important species in the South.

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CONTAINERIZED NURSERY START-UP COSTS

Mike Edwards[1]

INTRODUCTION

About 4 years ago, I seriously began to entertain the idea of opening a containerized forestry nursery. During this period, some of the timberland owned by American Forest Seed Service near Auburn University's Solon Dixon Forestry Center, located in Andalusia, AL, was being used for three out-planting test plots. The test plots compared growth rates between bareroot and containerized longleaf seedlings. Dr. Ken McNabb, a member of the Auburn University Forestry Staff, was in charge of this student research project. During one of his visits, I expressed an interest in growing longleaf pine (*Pinus palustris* Mill.) seedlings and asked his opinion of the possible start-up cost of a containerized nursery. He discouraged me, stating that it was an extremely high-cost business venture with a minimum start-up cost of approximately $250,000. Well, let me now confirm his statement...he was right. I only wish $250,000 were all I had invested in my start-up cost.

I, as a second year nursery owner, was asked to give a presentation on nursery cost because I am still in the midst of the struggle to make a "go" of it. If I am still in business after the second season of growing longleaf pine seedlings then I must have done something right, and therefore, I have been given time to share my new-found knowledge! What I am going to do is briefly share with you my experience in establishing start-up cost for my nursery with projected cost and income for the first 3 years of business.

DECIDING TO GROW LONGLEAF PINE SEEDLINGS

Two major considerations contributed to the decision to develop this nursery. First, there was the ideal location of Brewton, AL. Brewton is located within 75 miles of 20 percent of the remaining original longleaf stands. In addition, Brewton provides ideal growing conditions, seed sources, and local markets for seedlings. This broad market includes individual landowners, pole-lumber pulp mills with land bases, and military facilities. The second consideration was 4,000 plus acres of family owned timberland, one-third of which are longleaf pine stands. It was our goal to use seed from those stands and grows seedlings at this nursery to reforest the remaining acreage in longleaf pine.

With these goals and favorable conditions in mind, I began to research existing growing technology using containerized growing systems. I began my initial fact finding by contacting two very experienced people in the field of growing longleaf seedling crops. Philip Wilson of the Alabama Forest Commission's E. A. Hauss Nursery, a 25-year veteran, and Dale Larson, Gulf States Paper Corporation's Green County Nursery, a 14-year veteran, were contacted. With their technical guidance, I began to compile information and pricing on a large array of items from growing containers and planting equipment to shipping boxes.

PLANNING AND DEVELOPMENT

The next process, planning and development, is a very personal one. It involved taking all this technical information and transforming it into my interpretation of how to get the job done. This stage needs to yield solutions that are workable, effective, and efficient, while remaining as economical as possible. In other words, the solutions need to work effectively; using the minimum amounts of everything to be able to afford all that is needed. Planning in this necessary economical manner must be done with great thought for immediate and future growth. For example, planning for a nursery with the initial intent to grow 800,000 seedlings in the first crop with future growth to 2,000,000 seedlings is somewhat different from planning a nursery with the initial intent to grow 2,000,000 with future growth to 10,000,000. The planning is different because the objectives are not the same, even though starting a containerized nursery is the same primary objective. Planning the smaller nursery could be carried out with a much more economical approach such as seeding the crops with hired seasonal or contract labor. The larger nursery would likely need to obtain mechanical planting equipment for increased seeding speed and to reduce labor costs. The handling of growing trays would also be different in each nursery. The smaller nursery could approach the task by hand-carrying trays to elongated, constructed wire tables (being the most economical tables to use), while the larger nursery would need a more mobile approach that would initially be more costly. The mobile approach would improve timing and reduce immediate/future labor costs. My nursery development goals were based on the larger nursery scenario, resulting in the necessity to develop a mechanical seeding ability accompanied by a mobile growing system, adding to the initial cost.

SELECTIONS AND DESIGNS

I selected a 45-cavity Regi-pot® container for my growing season and designed a mobile growing module that supports 64 of these units. Using this module in an 18-growing module configuration, I laid out two growing fields. An injection irrigation system was designed to water these two fields. Two deep-water wells were required to water both fields.

I am sharing these intricate details to illustrate all the designing, detailing, and selecting that must take place in

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the planning and development process before the pricing and budgeting process can begin.

PRICING AND BUDGETING

Developing cost projections is the next process. This is a nursery cost projection based on Dr. McNabb's $250,000 nursery start-up cost. Note that each category covered is based on information accumulated in the planning and development process. Nursery site preparation cost, well cost, irrigation system cost, container cost, and so on. Each category is broken down and is then priced to form the total cost projection. Table 1 contains a summary of all of my costs associated with growing 3.3 million seedlings on two sites.

Table 1—Container nursery cost projections

Nursery site preparation			
Land and preparation			
1.5 acres per site (two sites)	$4,752		
Tractor grading costs	880		
Subtotal		$5,632	
Nursery road costs			
Entrance road coarse gravel (1,500 feet)	3,240		
Secondary road coarse gravel (800 feet)	1,080		
Road surface cover	2,916		
Tractor grading costs	1,424		
Subtotal		$8,660	
Nursery site preparation total			$14,292
Well and irrigation system			
Wells			
Deep well	4,600		
Growing shed well	1,500		
Subtotal		6,100	
Irrigation system			
Supply PVC sch. 40 and drain pipe	1,708		
Injectors (single)	1,872		
Timer, sprinkler heads 2" RPA back flow prevention	6,452		
Labor	6,000		
Subtotal		16,032	
Well and irrigation system total			22,132
Containers-52,000 trays			52,718
Growing tables-800			34,992
Planting and potting equipment (lease/purchase agreement)			10,959
Reconditioned fork-lift (lease/purchase agreement)			3,891
Barn/seed shed renovation			19,271
Pressure washer and tray washer			315
Potting soil-7,499 cubic feet			13,388
Longleaf seed-2.6 year supply			34,152
Refrigerated seed storage			1,000
Shipping boxes			10,125
Labor-planting/harvesting			49,440
Advertising-caps and brochures			2,499
Total			$269,174

COST/PROFIT & GROWTH PROJECTIONS

Start-up Years 1, 2 and 3

The final process, possibly the most critical, is calculating the cost, profit, and growth projections. These bottom-line figures must reflect calculated potential for immediate growth. It is extremely important to project these figures over a 3-year minimum period. Financing must be calculated past the first year, extending nursery financial needs into the second and third years. Nursery start-up cost should be based not on a first year period, but on a 3-year period. By planning extended budgets, unexpected low-yield crops that could prove to be critical to a first year can be made up or balanced out in a second or third year. A start-up nursery placing all available funding into a first-year effort without planning extended financing for the second season could lose it all because a first-year crop cannot be relied on to provide adequate financial returns to satisfy loans on first-year expenditures. The bottom line-adequate financial funding must be based on adequate planning and development with a 3-year projection of cost.

SMART START-UP FINANCING

1. Arrange financing for a 3-year period.
2. Consider leasing nursery equipment needed to achieve full tax deductions on equipment payments.
3. Nursery property—Consider having the nursery stockholders owning property utilized by the nursery. Additional profits can be realized by owner/stockholders, and it adds to tax deduction for the nursery.
4. Buy an adequate seed inventory for three growing seasons.
5. Seedling order deposits—Consider a client deposit on seedling orders that will at least cover seedling labor cost.

I should have warned you that budgeting and financial discussions talks are never interesting, but extensive planning and detailed cost projection equal adequate financing. Do not be caught short. Remember, every necessary need left out of a cost projection is monetary output not planned for!

UPDATE ON LONGLEAF PINE SEED SUPPLY MEETING

Mark J. Hainds[1]

This is an update of the activities following the September 1999 meeting concerning measures that were discussed to address the longleaf pine seed supply shortage. The people in attendance were Dr. Dean Gjerstad, Mark Haines, Robert Gandy, Larry Bishop, Dr. Ron Carey, Dr. Carey's graduate student Steve Oak, Dr. Jim Barnett, and Jill Barbour

An outline was developed and divided into short-term and long-term goals. Much progress has been made on the short-term goals and now it is time to address the long-term goals.

SHORT-TERM GOAL NUMBER 1: LONGLEAF PINE SEED PRODUCTION AREAS

The 1996 U. S. Forest Service publication, The Longleaf Pine Forest: Trends and Current Conditions, by Kenneth W. Outcalt and Raymond M. Sheffield SRS-9 Resource Bulletin, makes it possible to locate stands suitable for seed production. The report is based on information from the Forest Inventory and Analysis. Longleaf pine stands are identified by state, county, ownership, acreage, and timber size class. Trees in the sawtimber size class are most likely to be large and old enough to produce cones. The exact stand location can be pinpointed with the assistance of county foresters and county records. The publication needs to be reprinted because all the copies have been distributed.

A primer on the establishment and management of longleaf pine seed production areas has been written by Jill Barbour. It includes past research and current practical information needed to be successful at cone collection in the woods. It is now being reviewed and edited for content. The paper is targeted at the novice cone collectors, who want to begin collecting cones, and to the experienced collectors to further refine their technique.

SHORT-TERM GOAL 2 AND 3: SEED DRYERS AND CONE PROCESSING TECHNIQUES

These two areas were assigned to the personnel at the National Tree Seed Laboratory because they have the expertise in this area. Developing inexpensive cone dryers and seed dryers for extracting seed from bumper cone crops is the area where the most bottlenecks occur in the cleaning process.

Workshops specifically targeted at longleaf pine cone conditioning have been conducted and more are planned in the future. Only one workshop per year is being taught due to time restraints on personnel and the limited conditioning season. Drying cones and seed with information from psychometric equipment and charts are being taught in the workshops. A specific gravity cylinder built out of PVC was designed and constructed by Bob Karrfalt at the National Tree Seed Laboratory. Graduated cylinders are normally used for this procedure except that cylinders large enough to float longleaf pine cones do not have fine enough graduations to calculate specific gravity. The instructions to build the cylinder are being distributed and will be published in Tree Planters' Notes for future reference.

Building plans for an inexpensive seed dryer still needs to be developed. Inexpensive drying systems need to be investigated before the next bumper crop. Alternative drying systems could be tobacco barns, heated warehouses with fans, or poly greenhouses.

SHORT-TERM GOAL 4: SEED QUALITY

Steve Oak is continuing to identify insect and pathogens of longleaf pine seed that reduce germination. He is working cooperatively with graduate students at Auburn University. Michelle Cram, pathologist with the Forest Service, is working on longleaf pine seed problems as they relate to nurseries.

SHORT-TERM GOALS 5 AND 6: PROPERTIES OF SEED AND STORAGE

Dr. Barnett has compiled his research on longleaf pine cone and seed conditioning into one publication. It is currently being edited and reviewed. The paper is targeted at the novice longleaf pine grower and seed handler. It will be available as a research bulletin and eventually put on the Internet.

LONG-TERM GOALS

The long-term goals need to be addressed now that progress is ongoing with the short-term goals.

LONG-TERM GOAL 1: CONELET ABORTION

Longleaf pine is notorious for aborting a large proportion of its conelets a couple of months after pollination. If this problem could be solved it would greatly reduce the seed shortage. Dr. Hare was successful in reducing conelet abortion with Cytex (kinetin). In 3 separate annual tests, Cytex increased first-year conelet retention from 33 to 62 percent, 51 to 78 percent, and 53 to 72 percent (with boron).

Conelet abortion could also be a result of insect predation. Dr. McLemore studied 1,000 flowers and only 1 conelet remained after 7 months. Dioryctria was identified as the

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primary predator. Conelet abortion may be a combination or interaction of insect predation and cytokinin activity. Before operational recommendations can be made the cause still needs to be discovered.

A study plan needs to be developed to address this problem. To replicate Dr. Hare's work, the Cytex should be applied in a longleaf pine seed orchard that has been sprayed with pesticides. A one percent Cytex solution can be applied operationally with a mist blower. Once the proper procedure is established then other orchards can be added. It would be interesting to try the solution on cone producing trees in the woods. Due to the height of mature trees, an airplane or helicopter may be necessary for the solution to reach the crown.

LONG-TERM GOAL 2: SEED ORCHARDS

It is easier to collect cones in orchards than from trees in the woods because seed orchards are specifically designed and managed for seed collection. In 1981 there were approximately 443 acres of longleaf pine seed orchards. Some are grafted and the others are thinned progeny tests.

The current demand for longleaf pine seedlings exceed 125 million per year. This equates to 208,333 bushels per year or 50,000 pounds of seed annually based on a 50 percent germination rate. Approximately 5,208 acres of seed production areas would be needed to supply the seed assuming there is 5,000 seeds/lb., 40 seeds/cone, 30 cones/tree, and 40 trees/acre. The periodic cone crops precludes the production of 50,000 pounds of seed per year.

The Forest Service needs to keep their longleaf pine orchards and seed production areas open for public use. If the Forest Service cannot pay to manage orchards and seed production areas, maybe a cooperative can be formed that can take over the management. Since the demand is so strong, the Forest Service should identify more stands that can be converted to seed production for the public's use. Since one third of the longleaf pine resource is on Forest Service land, it is imperative that the Forest Service be involved to meet the future demand for seed.

There is a need to resurrect the research on longleaf pine genetics and the development of seed orchards to augment the seed production areas. Ninety seven percent of the longleaf pine acreage is gone and it is not known how much more can be removed before genetic diversity is at risk. Clone banks are owned by the Forest Service, the Western Gulf and University of Florida forest genetics research cooperatives. What is going to happen to these clone banks in the future? Will landowners, who want to establish longleaf pine seed orchards, have access to this genetic material?

When the seed is in short supply, the available seed will be planted anywhere without regard to seed source. The landowner may receive a seed source not adapted to his or her area, and the result will be poor tree growth and/or survival. Long term studies have shown that the species is not as genetically diverse as loblolly, so seed sources can move great distances east or west without an adverse effect on growth or survival. Even so, the sources in southern Florida do not perform well farther north; north Alabama sources do not perform well planted south; and Louisiana sources are more susceptible to needle blight fungus. It is questionable how well North Carolina and South Carolina sources will grow further south.

LONG-TERM GOAL 3: FERTILIZATION

Fertilization of longleaf pine trees to stimulate flowering works at some locations and not others. It has even been shown to be detrimental to the production of male flowers in one location. Fruitfulness may be more a function of temperature than nutrient fertility. Locating seed orchards and seed production areas in the southern part of the species' range where there is less chance of winter freezes may be the solution. Pollen may be more a limiting factor than fertilization since the orchards and seed production areas may not be located near other longleaf pine stands for supplemental pollination. There is still much that is not known about what stimulates longleaf pine to produce flowers and pollen.

LONG-TERM GOAL 4: RESEARCH

As the seed supply dwindles, the cone surveys conducted by Dr. Boyer become even more important. Will someone carry on the cone surveys? Past Forest Service research on longleaf pine reproduction needs to be resurrected and additional research needs to be conducted to fill in the gaps in our knowledge.

The biggest question is how to get the funding and who will conduct the research. The Longleaf Alliance only has funds to act as a clearinghouse for information. Funding sources need to be aggressively sought.

LONG-TERM GOAL 5: SEED CERTIFICATION

When there is a critical seed shortage, growers are going to buy the seed wherever they can and not worry about the seed source. The landowners have to plant what is available and probably never know the seed's origin. It is advised not to move seed sources more than one seed zone north or south. I'm not sure if seed certification is necessary with longleaf pine since there is more genetic diversity within populations than among populations. Seed and seedling certification is done by the state crop improvement associations. The certification fees are fairly nominal. A system to certify growers does not currently exist.

LONG-TERM GOAL 6: VEGETATIVE PROPAGATION

The area of micropropagation and vegetative propagation could greatly take the pressure off the need for large quantities of seed. Artificial regeneration can produce a large amount of seedlings with a smaller amount of seed than natural regeneration. Will longleaf pine cuttings produce roots and is the procedure the same as rooting the other southern pines? Rooted cutting would not have a grass stage so different site preparation and planting techniques will be needed.

LONG-TERM GOAL 7: INSECT PREDATION

The extent of insect predation on longleaf pine cones is not as well known as with loblolly and slash pine. Insect monitoring is usually not done in seed production areas. We need to know how much of longleaf's cone crop loss is due to insect predation. Cone insects may have a deleterious effect at one location but not at another location. Information from seed orchards could be collected on cone insects with monitoring system devised by Dr. Carl Fatzinger. It has been shown that pesticide applications can save 85 percent of the cone crop in loblolly and slash seed orchards.

CONCLUSION

Good progress is being made on addressing the seed supply shortage. Much work has been accomplished on the short term goals since the September 22, 1999 meeting in Jesup, GA. Annual seed conditioning workshops are being held and information is being compiled into resource bulletins. A symposium addressing the seed supply shortage would be a good way to compile information into one resource for the public.

A letter addressing the research needed to solve the seed shortage still needs to written to the USFS technical transfer liaison to Forest Service research.

Even with these efforts there is still a critical seed shortage. It will take a regional effort from organizations to really solve the problem. To be truly successful the Forest Service national forest system needs to allow seed dealers more access to longleaf pine of cone producing age. Stands could be converted to seed production areas with seed dealers managing the stands. The southern research stations can help the public by finding solutions to the problems associated with longleaf pine cone production.

IDEAS TO SOLVE THE LONGLEAF PINE SEED SHORTAGE PROBLEM

Short-term Goals:

1. Locate and establish more seed production areas (SPAs) needed by state
   a. identify existing SPAs by state and ownership
   b. develop maintenance regimes on how best to manage SPAs
   c. how to stimulate seed production
   d. estimating cone crop and maturity
   e. conelet abortion—how to reduce
   f. determine the amount of acreage needed in the species range and by state or seed zones
   g. determine how much seed is needed to meet the demand
   h. role of Forest Service land in developing SPAs
2. Not enough cone dryers for bumper crops.
   a. identify inexpensive ways to dry large cone crops
   b. build models
   c. test alternative ways to dry cones and monitor success
   d. construct inexpensive structures to store cones before drying
   e. teach how to use psychometric equipment and charts.
   f. distribute a list of suppliers for products
3. Seed dryers
   a. distribute building plans for constructing a seed dryer
   b. test alternative ways to dry seed so cone dryer is freed up for cone collection
   c. hold workshops to demonstrate cone processing techniques
4. Seed quality
   a. insects and pathogens
   b. seed damage
5. Cone crops
   a. what stimulates cone production?
   b. how to stimulate cone production
   c. insect control
   d. collection procedures
   e. how to predict when cones are ready to collect
6. Storage
   a. storage of cones before extraction—already known
   b. storage of seed—moisture content—already known

Long-term Goals:

1. Conelet abortion
   a. expand Dr. Hare's work on applying cytokinins on conelets
   b. need to try his recommendations over different soil types and climates to see if it works for all locations
2. Seed orchards
   a. how many acres do we need to meet demand?
   b. are research co-ops going to get involved in clonal selection?
3. Fertilization
   a. does fertilizer work with species?
   b. does fertilizer only work on certain soil types?
4. Research
   a. what research needs to be done and who will do it?
   b. who has money to fund research?
   c. applied versus basic
5. Seed certification
   a. identify collections by seed zone
   b. label plants by seed zone
6. Vegetative propagation
   a. micropropagation
   b. rooted cuttings
   c. needle fascicles

LONGLEAF PINE SEED QUALITY AND PREPARATION FOR SOWING

Robert P. Karrfalt[1]

ABSTRACT—The ability to run a highly efficient container nursery is heavily dependent on having excellent seed quality. Longleaf (*Pines palustris* Mill.) seed quality, although frequently poor, can just as easily be high if care is taken to meet the biological requirements of this species at all steps from seed collection through preparation of seeds for sowing. The necessary actions to take at each step in the seed handling process are described.

INTRODUCTION

"Quality seed does not cost, it pays" is a saying known in seed quality circles. It is true in bare root tree nurseries and vitally important to container growers. Every empty cell in the container nursery increases cost without contributing to revenue. Sowing extra cavities might give enough trees but does nothing for cost reduction. Therefore, there are three alternatives. Sowing two or more seeds per cell and thinning out the extra seedlings is one. This option incurs additional labor cost in thinning. In times of short seed supplies, this also becomes too expensive and wasteful in terms of direct seed costs. Sowing extra seeds in a side flat and transplanting them into the empty cells is a second. This also raises labor costs and may not give satisfactory results because the timing of transplanting is very critical for proper growth and timing with the main crop. The final alternative is to use seed of as high a quality as possible and give it maximum care. This option minimizes labor costs and maximizes the number of full cells. This paper covers the steps involved in high quality seed handling from collection through storage to sowing.

CONE COLLECTION

Timing of Cone Collections

Collection of cones is the first step in producing high quality longleaf pine (*Pines palustris* Mill.) seed. In the vast majority of cases, longleaf cones must be taken from the tree very close to their natural maturity date. Loblolly (*Pines taeda* L.) and slash pine (*Pines elfotti* Engelm.) can be collected early and after-ripened artificially. This is not the case for longleaf pine. This has been the finding of formal research (Barnett 1976a, McLemore 1975) and operational work. Hurricanes have blown good cone crops down periodically four to six weeks before natural seed maturity. Seeds from hurricane cones have germinated well at the National Tree Seed Laboratory (NTSL) on only one occasion. Early collected cones can be dried and the seed extracted; however, the seeds are not able to germinate well. Therefore, only mature cones should be picked from the tree.

Determining when the cones are ready for harvest is estimated using specific gravity. This is because the specific gravity is proportional to the water content of the cone, and water content decreases as the cone matures. The specific gravity of any object is defined as the weight of the object divided by the weight of an equal volume of water. For example, a cone weighing 100 grams would displace 100 ml of water. If the volume of this cone were 100 cubic centimeters (also 100 ml) then the specific gravity would be 1.0. The cone would neither sink nor float. Rarely if ever would this be seen. Green cones will sink because their specific gravity is greater than 1.0 and float as they mature because the specific gravity is less than 1.0. When cones just float in water the specific gravity is about 0.98. This means maturity is close.

Wakely (1954) determined that when 19 of 20 cones collected in a stand had specific gravities of 0.89, the harvest should begin in that stand. This measurement must be made within 20 minutes of removing the cone from the tree to give an accurate reading. This quick measurement is required because the cones will be drying, and any delay would cause the specific gravity to be measured below what it actually was on the tree. This specific gravity can be measured with motor oil, but water displacement is more convenient.

Measuring Specific Gravity

A simple field method of measuring specific gravity is to use a cylinder slightly larger in diameter than the cone. Three-inch pvc pipe works well. A toilet flange with a knock-out plug makes a good base and plug for one end of the pipe. A 1/4 to 1/2 inch drainpipe is installed on the side near the top of the cylinder. Water is put into the cylinder until it flows out of the drainpipe. The cone is then slowly lowered into the water and the overflow caught in a 100 ml graduated cylinder. The volume of water displaced from the cylinder by the floating cone is the weight of the cone. Record this volume. Next, the cone is pushed below the surface of the water displacing more water. This second amount of water equals the volume of the cone (or the weight of "an equal volume of water") that is needed for specific gravity measurement. Dividing the first volume by the second volume gives the specific gravity.

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POST HARVEST STORAGE OF CONES

Storage Conditions

Freshly harvested cones need to be protected from intense heat and allowed to continue drying. This means that good aeration must be supplied. This can be supplied by keeping the cones in burlap sacks, 20-bushel crates, or on drying racks. If the cones are in burlap sacks, they need to be up off the ground and not piled on top of one another. Therefore, they need to be on racks or on pallets where air can circulate completely around the bags. It is important that cones that have begun to open not be left out in the rain because the seeds can easily sprout while in the cone and a very significant loss in quality will result. Freshly picked cones should not be left in vehicles, such as closed trailers or vans that could heat up in the sun. Fresh cones are also high in moisture and still generally green in color. Therefore, they will be respiring and should not be left without ventilation for more than a brief period not to exceed 24 hours.

Length of Storage

Finding proper post-harvest cone storage conditions is important but only the first requirement to successful post harvest storage. The second requirement is drying the cones and extracting the seed within 30 days of harvest (Barnett 1996). Some cones have been operationally processed beyond 30 days but not successfully beyond 45 days. In one observed case in the field, the germination dropped from the lower 90s into the upper 80s between day 30 and day 45. A 10 to 15 percent drop in germination is a very large trade off for extending the extraction period. Completing the process in the recommended 30 days is best. All efforts possible need to be placed on extraction. If the 30-day period cannot be met, it is usually better not to collect the cones. The seed quality will be compromised in extending post harvest storage beyond 30 days.

On the other side of the equation is the fact that a two or three week post harvest storage period will increase seed yield (Barnett 1996, McLemore 1975), especially if the cones were collected a bit early. The compromise that must be struck then is one of quality versus yield. The largest differences in quality are manifested apparently after storage of one year or longer. Therefore, to meet current year needs one might decide to hold the cones to increase yields, while for future year needs the cones should be done as soon as possible to maximize storability of the seeds. A dual strategy might be to store the first seed extractions for the future and use the extractions made at 30 to 45 days for current or possibly second year needs.

One factor that has not been examined is the reprocessing of cones that have been closed by moistening. The lower yields from immediately processing twice might increase kilning, and still avoid the decrease in quality that occurs from too long a post-harvest storage period. Yields would be expected to increase, as they are known to do with other conifer species. The effect on seed quality would be totally speculative without research. This concept has not been tested. Once the seed is extracted from the cones, it can be dried and stored in an uncleaned condition until a later time without losing germination.

EXTRACTION OF SEEDS

Drying Cones

What are the requirements for drying cones? The main requirements are that the cones be provided enough space that they are able to expand freely and that there be free and even movement of dry air over the cones. This means that they cannot be more than two cones deep in drying trays, and if in bags, the bags cannot be more than half full of green cones. The best device for drying cones or seeds is a pressurized drier. Uniform drying is ensured in this device by forcing air from the bottom up through the seeds or cones. Blowing air over the surface of the cones can also be effective, but the pressurized drier is the preferred method.

What is meant by dry air? Often this has been interpreted to mean hot air. Although it is often easiest to dry air by heating, the question of how hot is not often asked. Table 1 shows how different ambient air conditions will require different amounts of heating. Using the lowest temperature possible is both more economical and better for the seed. To use this table the temperature and relative humidity out-of-doors need to be measured. The temperature is then located in the far left column of the table. Next, follow along that line to the right until the number in the body of the table is larger than the measured relative humidity. Move up that column to the top row. This top number is the temperature that must be obtained in the cone drier to obtain air at 30 percent relative humidity: This is the relative humidity needed to dry cones in 24 to 48 hours. Very little drying will occur when the relative humidity is above 50 or 60 percent. For an outside temperature of 22 °C (72 °F) with 65 percent relative humidity, the drier temperature should be 35 °C (95 °F).

Exactly how long it takes to dry cones is also dependent on how moist the cones are when placed into the kiln. Cones kept in 20 bushel crates usually take 48 hours to dry because they are still quite moist. Cones that have been stored in cloth sacks or on drying racks will be partially dried and can usually be dried in 24 hours, sometimes even in as little as 8 hours after prolonged air drying.

Tumbling Cones

When the cones are dry enough they open to release the seeds. Cones are then tumbled in some manner to shake the seed loose from the cones. This step is called extraction. Customarily this extraction step is done in a round cylinder that is perforated to allow the seed to fall free from the cones and the cones then directed away from the seeds. Various shaker tables have also been used with good success. At this step and all subsequent steps, it is very important not to mechanically damage the seeds. Longleaf seeds have very fragile seed coats that crack easily. High quality seed can be reduced to poor quality seeds in just a matter of minutes through poor handling that causes mechanical injury. Actions that rub the seed too hard or too long, drop the seed, pinch the seed between machine parts, or throw it against a hard surface will mechanically damage the seeds. Specific examples of machines that have been found by the NTSL staff to damage seeds are: bucket elevators scooping up the seed too fast, seed dewingers that use brushes or steel paddles and rub the seeds too forcefully, and vacuum conveyance of seeds.

Table 1—Chart for matching cone and seed drier temperature and relative humidity

Ambient air temperature		Drier temperature 24 (75)	27 (80)	29 (85)	32 (90)	35 (95)	38 (100)	41 (105)	43 (110)	°C °F
°C	°F									
4	(40)	100	100	100	100	100	100	100	100	
7	(44)	78	100	100	100	100	100	100	100	
9	(48)	66	86	100	100	100	100	100	100	Relative
8	(54)	57	75	98	100	100	100	100	100	humidity
11	(56)	50	65	77	88	100	100	100	100	
16	(60)	44	58	68	78	94	100	100	100	
18	(64)	39	51	60	65	84	95	100	100	
20	(68)	31	42	50	58	71	81	95	100	
22	(72)	30	38	45	49	65	68	82	100	
24	(76)	30	31	38	45	55	63	74	87	
27	(80)	30	30	35	38	47	54	64	75	

Drying Extracted Seeds

A second and very important factor to manage at the extraction step is drying the seeds. Longleaf seeds, unlike all other southern pine seeds, are shed from the cones at high moisture content. Seeds should not be stored at high moisture even for a brief time such as overnight. Seed deterioration takes place very rapidly at high moisture and germination and vigor begins to fall. This fact necessitates having a seed dryer immediately available to dry the seeds to a moisture content below 10 percent. Typically, 6 to 8 percent is obtained. Again, this is best done in a pressurized dryer, which was described previously in the paragraph on drying cones. Cones do not pack tightly together and can be dried in thin layers by simply passing air over the cones. It is not optimal, but can be an inexpensive alternative. Seeds, on the other hand, pack much more tightly together and require a pressurized dryer to dry the seed rapidly enough to prevent deterioration. Therefore, the dryer is indispensable at this stage. Dryer temperatures are selected in the same way as described above for drying cones.

Many requests have come to the NTSL over the years from persons who for several days could not dry their seeds. The root cause of the problem was usually that the outside air was too moist for the temperature used in the dryer. A higher temperature was needed to bring the relative humidity in the dryer to 30 percent. The second most common cause was leaking connections that allowed the air to escape from the dryer without going through the seeds.

A moisture test needs to be run on the seed to be sure the seed moisture is at a safe level for storage (below 10 percent) before drying is stopped. This is best done at the dryer with a moisture meter. Information on the meter and charts to use it are available from the NTSL. An oven moisture test should also be requested promptly from a qualified seed laboratory to verify the readings taken with the electronic meter. This is especially true if experience with the meter is limited.

Temporary Seed Storage

Once the seeds are at safe moisture content for storage they can be sealed in moisture proof containers so they will not absorb moisture from the atmosphere. If there will be more than two weeks before the final cleaning, seeds should be placed in cold storage that is at least 1.7 °C (35°F) and best if below freezing. If placed at freezing temperatures, the seeds need not be cleaned for several years. Delaying too long, however, increases storage costs because the raw seeds are very bulky because of the wings and take up two to three times more cold storage space than cleaned seeds.

DEWINGING, CLEANING, UPGRADING

Because of the risk of damaging seeds at the cleaning stage and the expense of the necessary equipment, it is best to leave the dewinging and cleaning of seeds to experienced persons. It is good to know, however, what equipment and what steps make for high quality seeds when selecting a contract seed cleaner. The first step is to dewing the seed. This is most often done in a mortar mixer or similar device that stirs the seeds. The mortar mixer is geared to run slower than it would when mixing mortar. The stirring action must be gentle. This requires good experience to know how long to run the seeds and how many seeds to put into the machine. Following the dewinging, the seeds must be cleaned to separate them from the detached wings and cone scales. Screening and air separation work well for this step. The final step to high quality seeds is to use the gravity table to remove partially filled seeds, and any remaining cone scales and empty seeds. The gravity table is a shaking inclined table with air blowing through it from the bottom. The poor quality products, bad seeds and cone scales, are slightly raised off the table surface by the blowing air and then they slide over the heavier good seeds that are pushed to the top of the incline by the vibrating table. The best seed then comes off the high end of the table and the trash from the bottom. X-ray analysis is needed to accurately adjust the gravity table and make the maximum improvement. The gravity table alone can produce seed germinating in the upper 80s and possibly lower 90s. By using x-ray analysis, germination can be in the mid to upper 90s. Of course, the gravity table cannot correct for poor handling at earlier stages. Every stage in the handling of the seeds from estimating cone maturity to the gravity table must be done correctly to have the high quality seeds needed in the container nursery. There can be no compromises without lowering seed quality.

TESTING AND SEED STORAGE

The finished seeds need to be placed in moisture proof containers to keep them dry. Metal or plastic can be used. Glass is least used because it is breakable and heavy. Cardboard drums and boxes with foil or plastic liners are most commonly used. Polyethelene liners need to be at least four mils thick. The liner or bag can be closed tightly with string, plastic tie, wire tie, or heat-sealed. The sealed seed container now must be placed into cold storage at about -8 °C (20°F) (Jones 1966). Colder temperatures can be used but are not likely of any value. Storage at -8 °C has been used successfully on an operational scale for decades. As mentioned earlier in this paper, testing the seed moisture content is critical for safe seed storage. A moisture test is inexpensive and is cheap insurance to protect seed viability. A moisture test should be taken initially upon sealing the seed for storage, whenever the seed is sampled for viability, and any time there is suspicion that the moisture content might have risen. Times of suspicion are when the container was damaged or opened. Because moisture content is the single most critical factor in maintaining seed viability, it would be ideal to test it annually. This has not proved practical and good seed management has been possible without annual testing as long as the storage container has not been broken open. When sending seed to a laboratory for testing, it must be placed in an unbreakable moisture proof container.

Other tests to do upon packaging the finished seed are germination, seeds per pound and purity. These are all important in determining the value of the seeds for sale and in preparing the correct amount for sowing. Germination and moisture content should be retested every three to five years in storage, within six to nine months before sowing, and before purchasing any seeds. Without testing, the grower simply takes a very big gamble on a crop failure caused by using low viability seeds. The viability needs to be as high as possible to minimize empty cell problems. Seeds per pound and purity can be expected to remain unchanged in storage and would not need to be retested. One exception would be if moisture has increased. Then the seeds per pound would have to be retested. How much water is in the seeds has a strong influence on the weight of the seeds.

PREPARING SEEDS FOR SOWING

How Much Seed to Prepare

How many pounds of seeds to prepare are calculated by dividing the number of seedlings desired by the germination, purity, and seeds per pound. The pounds are further divided by an additional factor called the survival factor. This is an estimate of the number of germinating seedlings that will live. To determine the survival factor, count the exact germination in several trays scattered across the nursery at weekly intervals. Any dead seedlings should be noted and recorded along with living seedlings. The dead seedlings should be removed at every count. Continue counts until no more germination occurs. A final end-of-season count will also be made. Divide the number of surviving seedlings by the number of seeds that germinated to obtain the nursery survival factor.

An example of these calculations follows: germination: 92 percent; purity: 99 percent; seeds per pound: 5,500; number of desired seedlings: 10,000; nursery survival factor: 97 percent. The pounds of seed to prepare equals: 10,000 seedlings / [(0.92)(0.99)(5,500)(0.97)] = 2.05 lbs.

Chemical Treatment

Treating the seeds with chemicals has been found to improve germination. Benlate was reported (Barnett and others 1999, Barnett and Pesacreta 1993) to improve germination by controlling fungal problems. This chemical is not registered at the present outside of North Carolina. Gustafson 42s is another fungicide used as a seed treatment. It is registered for use on southern pine seed. It has been reported by growers that birds are less likely to feed on the seeds if treated with Gustafson. Hydrogen peroxide in 30 percent concentration can also be used as a seed sterilant (Barnett 1976b). However, it was found to be no better than Benlate (Barnett and others 1999) and is dangerous because it is a very strong oxidant that can cause skin and eye injuries. Whatever chemicals may be used, be sure to use only registered materials and follow the label.

Cold Stratification

Cold stratification of the seeds is also reported to improve germination (Karrfalt 1988). As this is not a procedure traditionally used for longleaf seeds, both Karrfalt (1988) and Barnett (1996) advised caution or described damage to germination from stratification. In a desire to improve longleaf seed performance, however, the NTSL and numerous growers compared using stratified seeds and unstratified seeds. As a result, most longleaf seed tests done at the NTSL are now stratified because the lab results are higher and there is better correlation between the lab test and the field germination. Hundreds of tests at the NTSL support this practice. Several nurseries are now routinely using stratification to obtain better germination. Adoption of this procedure should be made with caution.

It is very important to do stratification correctly. Longleaf is not a forgiving species and will not tolerate poorly applied procedures. The first step is an overnight water soak. This should be in a cool area. The soak brings the seeds to adequate moisture content to begin preparing to germinate The next steps are very important to prevent germination. They must be surface dried. This means the removal of all free water around the seeds without drying the seeds themselves. The seed coats will look damp but not shiny when correctly dried. Second, they must be sealed in a moisture proof container to prevent drying. They should not be in layers more than two to three inches deep so that heat of respiration can dissipate. Finally, they must be kept in a well-controlled cooler between 0.6 °C (33 °F) and 3.3 °C (38 °F). They cannot freeze nor be warmer than 3.3 °C (38 °F). A cooler that is frequently opened is not suitable because it will not hold temperature. Caution is advised when beginning to use stratification. It must be done correctly. A small trial section is best done first to learn the technique and be sure it works in your operation. A failure may point out where improvements need to be made or that it is not suitable for your nursery. Success with stratification may on the other hand lead you to a larger trial and to full acceptance of the procedure.

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REDUCING SEED AND SEEDLING PATHOGENS IMPROVES LONGLEAF PINE SEEDLING PRODUCTION

James P. Barnett and John M. McGilvray[1]

ABSTRACT—The demand for container longleaf pine (*Pinus palustris* Mill.) planting stock is increasing across the Lower Gulf Coastal Plain. Poor-quality seeds and seedling losses during nursery culture further constrain a limited seed supply. Improved seed efficiency will be necessary to meet the need for increased seedling production. We evaluated seed presowing treatments and seedling fungicidal applications in container longleaf pine seedling operations to determine if efficiency of seedling production could be improved. Application of treatments to reduce pathogenic fungi on seed and in seedling culture significantly increased plantable container stock.

INTRODUCTION

With a 10-fold increase in seedling production occurring in the last few years, interest in the production and planting of longleaf pine (*Pinus palustris* Mill.) seedlings has reached an all time high. A limitation in producing even more seedlings is lack of high-quality seeds that not only germinate well, but result in plantable stock. Earlier results have shown that longleaf seed coats carry pathogenic fungi that not only reduce germination, but also result in significant seedling mortality (Barnett and others 1999). Pawuk (1978) and Fraedrich and Dwinell (1996) found that *Fusarium* sp., which are commonly found on longleaf pine seeds cause longleaf seedling mortality. Tests have shown that treating longleaf seeds with a sterilant or fungicide prior to sowing can improve both germination and seedling establishment (Barnett 1976, Barnett and Pesacreta 1993, Littke and others 1997). However, the effects of using both seed pretreatments to control seed-coat pathogens and fungicides to minimize seedling losses during the cultural period have not been reported. Our objectives were to develop recommendations for presowing treatments and fungicidal applications that will improve the efficiency of seedling production.

METHODS

The seeds used originated from bulked seed orchard lots of longleaf pine adapted to the Western Gulf Coastal Region. We grew seedlings at the Southern Research Station's facility at Pineville, LA, following guidelines for producing longleaf pine container stock (Barnett and McGilvray 1997).

We grew seedlings in Multipot 3-96™ containers and evaluated both seed presowing treatments and seedling fungicidal applications. The presowing treatments were a control and a hydrogen peroxide application—1-hour soak in 30-percent hydrogen peroxide (Barnett 1976, Barnett and McGilvray 1997). The seedling fungicide treatments included: (1) a control, and applications of (2) Benlate®, (3) Fungo-flo®, and (4) Fungo-flo® plus Subdue®. The fungicides were applied biweekly after seed germination was complete. The recommended concentrations of the fungicides used are: Benlate® 50WP (benomyl)—1 rounded teaspoon per gallon of water; Fungo-flo® (46.2 percent a.i. thiophanate-methyl)—0.2 fluid ounce per gallon of water; Fungo-flo® plus Subdue® 2E (metalaxyl) at 10 ppm active ingredient (0.15 mL per gallon of water).

The study was a randomized experiment with three replications of three trays each for each treatment replication. We included a total of 72 trays of 96 seedlings each in the study. We sowed the seeds in late April 1999 and made seedling counts in December 1999 to determine the percentage of plantable seedlings (number of cavities with a plantable seedling divided by number of cavities with a germinant). Plantable seedling percentages differ from germination percentages in that losses of germinants due to disease are taken into consideration.

RESULTS

Both the seed and seedling treatments had a significant effect on plantable seedling percentages at the end of the study, and there were no statistical interactions between the presowing and fungicidal treatments (table 1). The hydrogen peroxide treatment of seed increased plantable seedlings from 85 to 93 percent; fungicide treatment of controls increased plantable seedlings from 78 to 92 percent. When we used the hydrogen peroxide seed treatment, 92 percent of the seedlings that did not receive fungicides were plantable. Fungicide applications to seedlings only improved average plantable stock by 2 percent.

Seedlings grown from seed that did not receive the hydrogen peroxide presowing treatment had a plantable seedling percentage of only 78, compared to 88 for those treated with fungicides during culture. There were no significant differences in the effectiveness of fungicides.

DISCUSSION

Results from this study demonstrate the effectiveness of reducing fungal populations on longleaf pine seed coats

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Table 1—Longleaf pine plantable seedling percentages resulting from seed and seedling treatments[a]

Seedling treatment	Seed treatment: Control	Hydrogen peroxide	Average
	------------------ % ------------------		
Control	78	92	85a
Benlate®	85	93	89b
Fungo-flo®	88	94	91b
Fungo-flo® plus Subdue®	90	94	92b
Average	85a	93b	

[a] Plantable seedling percentages (numbers plantable in November divided by numbers with an initial germinant) are averages for 288 seedling cavities for each of three replications. Averages within columns and across rows followed by the same letter are not significantly different at the 0.05 level.

before they are sown in containers. Elimination of pathogenic fungi from seed coats increases seedling establishment and reduces sources of disease infestation later in the nursery cultural period. Although 30-percent hydrogen peroxide used in this study is labeled as a stimulant of pine seed germination, earlier research has shown that a 10-minute Benlate® seed drench was equally effective and is a safer means of reducing seed coat pathogens (Barnett and others 1999). Benlate® has been labeled for conifer seed treatment in most of the southern States. Other fungicidal chemicals or methodologies also may be effective if they are not phytotoxic to seed germination.

There were no statistical differences among the fungicides used to reduce seedling losses during the nursery growing period. Because a great deal of research has demonstrated its effectiveness in controlling *Fusaria*, we used Benlate® as a kind of fungicidal standard. However, the label for this fungicide has been withdrawn for conifer nursery use. Fungo-flo®, a labeled replacement for Benlate®, is equally effective in controlling pathogens of longleaf seed and seedlings. Subdue® is normally added to the fungicidal application because it broadens the spectrum of disease protection to include other pathogens such as *Pythium* and *Rhizoctonia*.

Combing presowing seed treatments to reduce pathogenic fungi on the seed coats with the application of appropriate fungicides to seedlings during the growing season to control pathogenic fungi greatly increases the efficiency of container seedling production.

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ACTIVITIES THAT INCREASE GERMINATION AND ESTABLISHMENT OF LONGLEAF PINE SEEDLINGS IN CONTAINERS

James P. Barnett[1]

ABSTRACT—Critical to the successful production of longleaf pine (*Pinus palustris* Mill.) container stock is use of high quality seeds that are properly prepared and sown. Uniformity in germination and establishment in containers makes nursery production easier and more profitable for the grower. Activities that affect seedling performance include: time of seed sowing, sowing techniques, number of seeds sown per cavity, seed covering, and thinning and transplanting germinants. Recommendations for each activity are provided.

INTRODUCTION

Obtaining a uniform seedling crop is essential in producing consistently high quality longleaf pine (*Pinus palustris* Mill.) seedlings. If variability in seed germination and establishment is significant, the chance of producing a quality seedling is reduced. The first step to obtaining adequate germination (more than 85 percent) and acceptable losses after emergence (less than 10 percent) is the acquisition of quality seedlots. Poor germination and excessive losses prevent high quality crops because seed is wasted on oversowing. Unfortunately, many of the longleaf pine seedlots available to nursery managers do not produce adequate seedling germination or minimal seedling losses. Thus, the nursery manager must take additional steps to maximize germination and establishment in containers. Attention to the timing of seed sowing, sowing techniques, number of seeds sown per cavity, seed covering, and thinning and transplanting of germinants is critical to developing the best possible crop and to maintaining an economically viable operation.

TIMING OF SOWING

After obtaining the best available seed and applying appropriate presowing treatments (Barnett and McGilvray 1997), time of sowing is the next critical step in assuring good seed performance. Longleaf pine seeds are adapted in nature to fall germination, so the optimum germination temperatures are somewhat lower than those for the other southern pines (Barnett 1979). It is important, then, to avoid consistently high temperatures during seed germination. The optimum temperature range for longleaf seeds is 65 to 75 °F. Depending somewhat upon geographic location, the recommended sowing dates are April through early May. Sowing early, when temperatures of the medium are cooler, slows germination and exposes seeds over a longer period to damping-off fungi that may kill germinating seeds. Sowing late, when temperatures are routinely above 85 °F, reduces total germination.

SOWING TECHNIQUES

The scale of the operation determines whether the seeds are sown by hand, by simple templates, or by elaborate seeding machines. When production is within a few hundred thousand, hand seeding is completely feasible. When production expands into the millions, some sort of more automated seeder is needed. Even mechanical seeders must be visually checked after sowing to ensure that the prescribed seeding rate has been met. Because longleaf seeds have large wing stubs, uniform sowing is difficult.

NUMBER SOWN PER CAVITY

For maximum efficiency in nursery production, empty cavities must be avoided because all cavities, with or without seedlings, cost the same to carry through the growing cycle. But seed germination seldom approaches 100 percent, and some empty cavities will occur after germination is completed if only one seed is sown per cavity. Seed germination, labor costs, and possible long-term effects on field performance determine planting strategies. These include multiple-sow and thin or transplant, single-sow and transplant from germination flats, or to single or multiple sow and accept initial stocking levels. When a current germination test is 80 percent or more, the general recommendation is to sow one seed per cavity.

Situations also may arise when sowing of one seed per cavity is the best option; even when seed quality is low. An example is an inadequate seed supply—a frequent occurrence with longleaf pine. Another possible situation occurs when the labor force is inadequate for thinning or transplanting. If viability of the seedlot is in the 65 to 80 percent range (typical for many lots of longleaf pine), two seeds per cavity should be sown (Barnett and McGilvray 1997).

Balmer and Space (1976) prepared tables that use sowing rates and expected germination to predict the number of vacant and stocked cavities. These tables are useful when selecting sowing rates and estimating how much thinning will be required. For example, if germination tests show that

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expected germination is 70 percent, sowing two seeds per cavity can reduce the percentage of vacant cavities from 30 to 9 percent, but also will increase doubles to 49 percent. Sowing three seeds per cavity will further reduce vacant cavities to 3 percent, but will increase doubles and triples to 78 percent. To help minimize these problems, Pepper and Barnett (1982) suggest a mixed-sowing scheme. For instance; 30 percent of the containers could receive three seeds; 20 percent could receive two seeds, and the remaining 50 percent could receive one seed. Mixed-sowing schemes are generally more cost-efficient than the standard constant number approach, and vacuum seeders can usually be adjusted to seed the desired mix. However, mixed sowing will still require some thinning and transplanting of germinants to reach one seedling per cavity.

SEED COVERING

After filling and seeding the containers, most growers cover the seeds with a light layer of medium, vermiculite, or grit. This covering tends to restrict the development of moss and algae on the surface of the potting mix and improves the moisture relationships around the seeds, thus improving or hastening germination. Seeds should be covered by no more that 1/8 in. of material. Deep covering slows germination and increases the chance of damping-off and other disease problems (Barnett 1988).

The need to cover varies with the type of watering system. Germination is usually most complete and rapid when seeds remain uncovered and receive water by a misting system (Brissette and others 1991). If seeds are watered less frequently, which is usually the case, a light seed covering facilitates germination by mulching that retains moisture near the seeds and accelerates germination.

THINNING

If cavities are multiple-sown, the nursery manager must decide whether to thin. Thinning should be completed by the time seed coats are shed to minimize the effects on seedling development.

The short-term effects of leaving multiple seedlings in container cavities have been evaluated with longleaf, loblolly, and slash pine (fig. 1). The most marked effect was on seedling development—where multiple seeding reduced seedling dry weights by one-half or more at the end of a 14-week greenhouse-growing period. The smaller, multiple-grown seedlings also showed poorer survival after 3 years when compared to those grown with only one seedling per cavity (Barnett and Brissette 1986).

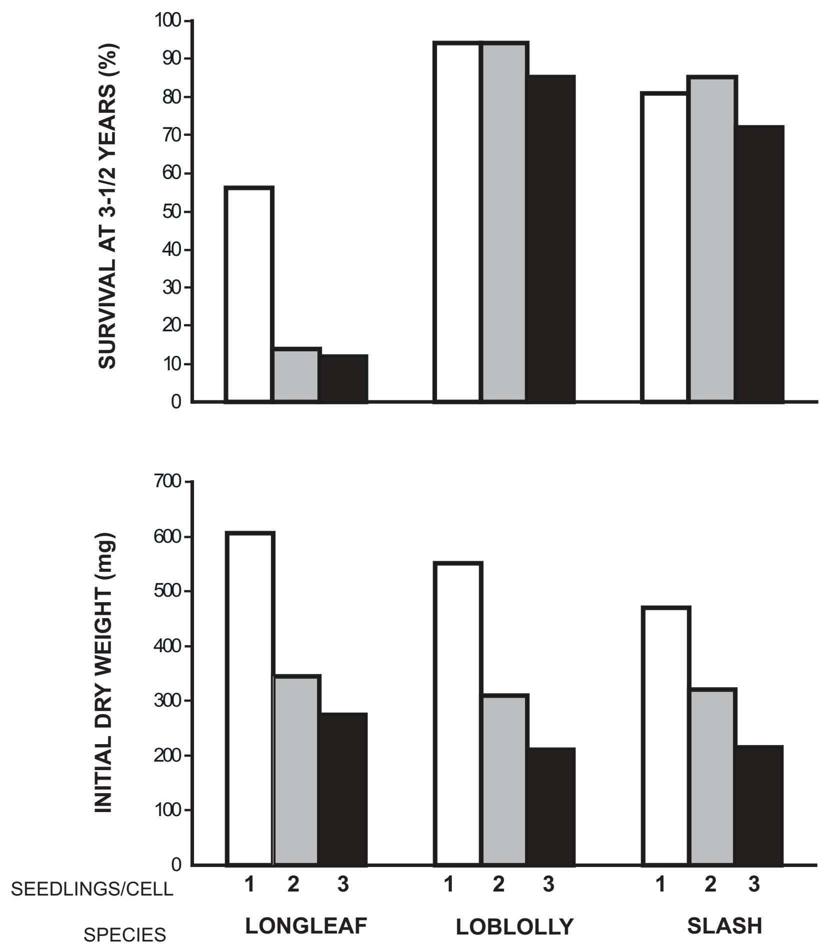

Figure 1—Initial seedling development 14 weeks after sowing in Styroblock 4 containers and field performance after 3.5 years.

TRANSPLANTING

If the percentage of cavities with ungerminated seeds is between 5 and 15 percent, transplanting germinants from cavities with multiple germinants or from germination flats is feasible but unnecessary. However, the absence of germination in up to 5 percent of the cavities will have little practical effect on costs. If more than 15 percent of the cavities are empty, the short fall should be made up by sowing additional containers.

Pawuk (1982) studied the effect of transplanting on initial seedling growth and development. His evaluations involved transplanting germinants with different lengths of radicle development: 0.6 to 0.8 in., 1.2 to 1.4 in., and 1.8 to 2.0 in. The germinants were transplanted carefully to avoid injury to tender radicles. Earlier observations have shown that damage to the radicle, such as breaking the tip, would slow root development and seedling growth. Transplanting longleaf pine germinants, regardless of their radicle length, was detrimental to subsequent diameter growth compared to nontransplanted controls (table 1). Total dry weight was directly related to radicle length when transplanted.

The importance of careful timing when replacement seedlings are transplanted into empty cavities is clear. Transplanting of a vigorous germinant should be done as soon as an empty cavity becomes evident, generally about 10 to 14 days after sowing. Replacements with short radicles are easier to transplant without damage than those with long radicles. If transplanting is delayed, germinants with longer radicles should be used because smaller seedlings are quickly suppressed at dense stockings. However, transplanting is best done before the seed coats drop and radicle elongation exceeds about 2 inches.

CONCLUSIONS

Uniform seedlings in fully stocked containers reflect successful nursery management. Because initial seed quality is often beyond the control of the manager, a number of sowing related activities under the control of the manager can improve the quality of the crop. Time of sowing and amount of seed covering have a significant impact on the development of uniform germination. These activities affect the optimum temperature and light requirements for germination. Decisions on sowing rates (based on seedlot quality) greatly influence a time-consuming and costly part of nursery production. If multiple sowing is required, thinning, transplanting, or both must be evaluated because only one longleaf seedling should remain in each cavity. The timing of thinning and transplanting is critical to obtaining quality seedlings that will survive and promptly grow taller. Nursery managers who pay attention to the activities described will increase germination and establishment of longleaf pine seedlings in containers.

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Table 1—Effect of radicle length at time of transplanting of longleaf pine and shortleaf pine seedlings after 15 weeks (adapted from Pawuk 1982)

	Longleaf pine		Shortleaf pine	
Radicle length	Root-collar diameter	Dry weight	Height	Dry weight
cm	*mm*	*mg*	*cm*	*mg*
1.5–2.0	1.12a	168a	6.61a	137a
3.0–3.5	1.20a	210b	9.36b	173b
4.5–5.0	1.28a	237c	9.48b	188b
Seeded (control)	1.48a	342d	9.93b	280c

COPPER-TREATED CONTAINERS INFLUENCE ROOT DEVELOPMENT OF LONGLEAF PINE SEEDLINGS

James P. Barnett and John M. McGilvray[1]

ABSTRACT—Development of longleaf pine (*Pinus palustris* Mill.) seedlings grown in Copperblock™ containers and BC/CFC First Choice™ Styrofoam blocks, with applications of Spin Out® root growth regulator, were compared to control seedlings. The copper treatments significantly changed seedling morphology; at outplanting, dry weights of both roots and tops were greater than for control stock. Evaluations made 30 days after planting seedlings in a sand stress-bed environment showed that root egress from the treated containers was greater than from the control.

INTRODUCTION

From the development and earliest use of container production technology, copper treatments have been used to modify root growth of tree seedlings. Early use was with seedlings grown in Paperpots™ to prevent root egress from the bottom of containers (Barnett and McGilvray 1974, Saul 1968), but soon researchers began evaluating the coating of interior walls of container cavities (McDonald and others 1984a, 1984b; Ruehle 1985). Without root pruning by a copper treatment, the root plug produces many roots on the outside of the plug, typically forming a "cage" with few roots in the middle and clustered root tips at the bottom of the container (Struve 1993, Watt and Smith 1999). Such root systems usually will produce new roots from the cluster of root tips at the bottom of the plug. These root systems may produce seedlings that are unstable after planting (Ruehle 1985, Struve and others 1994).

The use of copper-treated containers may improve root configuration. A copper coating on container cavity walls inhibits cell division at the root apex and inhibits root elongation at the root/container-wall interface (Watt and Smith 1999). An abundance of higher-order lateral roots is created, and their growth is stopped at the container wall. This results in a root system with many short, branched roots within the plug. After outplanting, root tips resume growth and produce a more branched root system. More roots are in the top 1/3 of the plug where they better exploit water and nutrient resources and result in better seedling stability (Ruehle 1985, Smith and McCubbin 1992).

Such means of root pruning have other benefits for container tree seedlings. Romero and others (1986) analyzed root development of copper-carbonate treated Caribbean pine (*Pinus caribaea* Morelet) and found that treated seedlings had more lateral roots, as well as significantly larger stem diameters, than control seedlings. They also noted a change in root morphology. Treated seedlings had finer, more fibrous root systems and were easier to extract from containers. However, the major benefits of chemical root pruning seem to occur after outplanting. Our study evaluated the effects on longleaf pine (*P. palustris* Mill.) seedling development when seedlings are produced in copper-treated trays.

METHODS

The seedlings originated from bulked lots of longleaf pine orchard seeds adapted to the Western Gulf Coastal Plain. They were grown at the Southern Research Station's research facility in Pineville, LA, following guidelines for producing longleaf pine container stock (Barnett and McGilvray 1997).

We grew all seedlings in Styroblock 112 containers and evaluated a control and three copper treatments. In two treatments we used Beaver Plastics' Copperblock™ containers (Beaver Plastics, 12150 - 160 Street, Edmonton, Alberta, Canada T5V 1H5) at 0.5x and 1x rates of copper application. The Copperblock™ containers are designed to leave a portion of the cell untreated. Wide untreated ribs extend from top to bottom of the cells. The third copper treatment was BC/CFC First Choice™ containers coated with Spin Out® (Griffin LLC, P.O. Box 847, Valdosta, GA 31603-1847). The Surrey Nursery in British Columbia applied Spin Out® to First Choice™ containers using a sprayer specifically designed to treat the entire inside cell walls. We grew seedlings in a 1:1 peat-vermiculite medium after sowing in late April 1999.

The study was a randomized experiment with five replications of two styroblock containers (96 cavities each) per treatment. Three-seedling samples from each replication were taken in mid-July and again in November to evaluate the treatment effects. We determined dry weights of tops and roots and measured root-area indices (RAI) using a Delta-T device area meter (Decagon Devices Ltd.) in July and 30 days after outplanting in a sand stress-bed. The RAI in July measured root systems washed from seedling plugs. We removed roots extending beyond the plug surface measured them separately at 30 days after outplanting. We conducted statistical analyses of the randomized treatments and determined differences at the 0.05 level of probability.

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RESULTS

The effects of the copper treatments on root development of longleaf pine seedlings differed by the time of year of sampling. When sampled in July (mid-season), top weights from the copper treatments were statistically greater than for the controls (table 1). Root-area indices of the controls were larger than for the copper treatments. Although control seedling weights were numerically larger than the treatments, the differences among root weights were not statistically significant. In November, seedlings grown in copper cells also had greater top weights than the controls. The root weights in copper cells were larger than in controls, but they were not statistically significant. Thirty days after seedlings were outplanted into sand stress-beds, root growth was greater for the copper treatments than for the controls.

Although research personnel made no mechanical measurements, those who removed seedlings from the containers reported that seedlings grown in copper-treated plugs were much easier to extract. Also, seedlings grown in Spin Out® cells were easier to extract than those grown in Copperblock™, either because the latter have untreated areas within cavities or because a less effective binding agent is used during copper application.

These results indicate that changing root morphology by coating cavity walls not only shifts root growth patterns by limiting root growth at the cavity wall-growing medium interface, but also affects seedling development. Early in the growing period, copper tends to reduce root weight development. Later, overall root weights in copper treatments are greater than in the controls. We believe that copper treatment results in more growth of the tap root as the length of lateral root growth is inhibited, but that the fibrous roots produced are better distributed within the container cavity. We did not evaluate the effect of copper treatment on nutrient status of the seedlings. Abundant nutrients were provided during the cultural period, so only if copper affected the balance of nutrients would seedling growth be affected.

CONCLUSIONS

The faster growth of roots from the seedling plug surface when outplanted indicates that field performance of seedlings grown in copper-coated containers may be improved. However, such field evaluations were not a part of this study. Other studies are underway to evaluate the field performance of longleaf pine seedlings grown in copper-treated containers.

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Table 1—Effects of copper-treated styroblocks on longleaf pine root development as measured in July, November, and 30-days after outplanting into stress beds[a]

	Mid-season (10 wks.)			Final (24 wks.)		Planting +30 days
Treatments	Top wt.	Root wt.	RAI	Top wt.	Root wt.	RAI
	- - - - - - - - *mg* - - - - - - - -		*cm²*	- - - - - - - *mg* - - - - - - -		cm²
Control	1.14a	294a	30b	2.89a	1.23a	93
CB 0.5x™	1.33b	239a	17a	3.60c	1.35a	122
CB 1x™	1.38c	224a	18a	3.46b	1.44a	111
Spin Out®	1.45d	273a	19a	3.67c	1.51a	191

[a] The values represent averages of 15 seedlings (3 seedlings each from 5 replications). The CB treatments refer to Copperblock™. Values within columns followed by the same letter are not significantly different at the 0.05 level. Insufficient replication of the Planting +30 days RAIs prevented statistical analysis of these data.

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INTERIM GUIDELINES FOR GROWING LONGLEAF SEEDLINGS IN CONTAINERS

James P. Barnett, Mark J. Hainds, and George A. Hernandez[1]

ABSTRACT—The demand for container longleaf pine (*Pinus palustris* Mill.) planting stock continues to increase each year. A problem facing both producers and users of container seedlings is the lack of target seedling specifications. Outplanting and evaluating performance of seedlings with a range of physiological and morphological characteristics, over a number of years, and on a wide range of sites is needed to have sufficient data to develop optimum seedling criteria. Since resources have been unavailable to conduct this needed research, we have canvassed the producers and users of longleaf container stock for their recommendations on what they consider "preferred" and "not acceptable" planting stock. The compilation of this information has been widely reviewed and all suggested revisions considered. These standards are proposed as guidance until research provides sufficient data to modify and upgrade the specifications.

INTRODUCTION

Interest in the production and planting of longleaf pine (*Pinus palustris* Mill.) has reached an all time high, and demand for seedlings continues to increase. A 10-fold increase in seedling production has occurred in the last few years. In year 2000, growers produced about 75 million longleaf pine seedlings. In the last few years, seedling users are increasingly concerned about the lack of recognized and accepted stock specifications for container longleaf pine seedlings. Establishing seedling standards based on research has been difficult because even substandard container stock will survive in years when rainfall is abundant. Developing seedling grades requires outplanting and performance evaluation of seedlings with a range of physiological and morphological characteristics—testing over a number of years and over a range of site conditions. Lacking the resources to conduct the research to establish standards, The Longleaf Alliance and two USDA Forest Service units—the Cooperative Forestry group in Atlanta and the Southern Research Station silviculture unit in Pineville—decided to seek agreement among producers and users on acceptable seedling criteria. A survey of those who produce and use longleaf pine container stock for their recommendations revealed that available information was insufficient to develop three different seedling grades similar to those for bareroot stock (Wakeley 1954). So, we decided to develop only two, "preferred" and "not acceptable."

Initially, we mailed an informal interview document to 15 longleaf growers and to the Southern States' Forest Management Chiefs for their suggested specifications. After compiling these responses, we prepared a preliminary document and circulated it among all growers, to the Forest Service's Southern Region, and to State silviculturists for comment. We evaluated the additional comments and incorporated them into the proposed standards.

We propose these standards as interim guidance until research provides sufficient data to modify and upgrade the specifications.

THE INTERIM STANDARDS

The interim standards in table 1 are only guidelines. Seedlings that fail to meet the criteria for the preferred category may still survive and grow well under favorable site conditions. However, experience has shown that when seedlings meet the preferred criteria, they will perform well in more stressful situations or less prepared sites. As additional research information becomes available, we will develop more specific criteria and will modify and improve these interim guidelines in the future.

The short discussion of seedling characteristics that follows should help clarify some of the issues related to the criteria listed in the standards.

NEEDLES

Size and condition of the needles are important to future survival and growth. Most seedlings are grown under nutrient regimes that limit excess growth, eliminating the need for clipping needles. To maximize root-collar development, some growers may use heavier fertilizer regimes. Such regimes may result in excessive needle growth and require needle clipping, especially if needles reach 12 to 16 inches. At this length, they tend to fall over and lodge, causing problems in uniformity of irrigation and increasing the likelihood of disease development. If clipping is required, growers should not cut needles shorter than 5 or 6 inches to maintain seedling growth and root-collar development (Barnett and McGilvray 1997).

The presence of needle fascicles indicates a well developed seedling. If needles develop in clusters of two or three, the seedlings will perform well when planted. Generally, needles should be pale to dark green in color. However, seedlings

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Table 1—Interim specifications for longleaf pine container seedlings

Characteristics	Preferred	Not acceptable
Needles		
Length if not top clipped	8 to 12 inches	< 4 inches
Length if top clipped	6 to 10 inches	< 4 inches
Fascicles	Many present	None present
Color	Medium to dark green	Yellow or brown
Roots		
Root collar diameter at base of needles	≥ 0.25 inch	< 3/16 inch
Color	Light brown with white tips	Black (diseased)
Mycorrhizae	Present (the more the better)	
Evidence of disease	None present	Any present
Root spiraling	None present	Any noticeable amount
Buds		
Present	Present on 90 percent of crop	Absent
Color	Green to brown	Yellow or chlorotic
Container attributes		
Container size (per plant)		
Diameter	≥ 1.5 inches	< 1 inch
Length	≥ 4.5 inches	< 3.5 inches
Volume	≥ 6 cubic inches	< 5.5 cubic inches
Other important attributes		
Firmness:	Plug stays intact when extracted and during handling; no loss of potting medium.	
Moisture:	Root plug is always moist, never dry.	
Pests:	No competing weeds or insects are present.	
Sonderegger:	Buyer specifies whether to cull Sonderegger seedlings.	

grown in northern nurseries may have variations in color that result from exposure to cold temperatures. Yellowish needles indicate poor seedling vigor.

ROOTS

Root-collar diameter (RCD) is one of the best indicators of seedling quality. Seedlings with RCDs of 0.25 inch or larger should survive well and invariably reach the 1-inch diameter needed for height growth earlier than smaller seedlings. Observation of roots requires more attention than observation of tops. Roots with light brown color and numerous white tips indicate vigorous seedlings. Black roots require close scrutiny because they are likely to be diseased, particularly if a large portion of the root system is black. If the cambium is brown when the root is scraped with a fingernail, the root is dead. Waterlogging in the bottom of a container—caused by roots plugging the drainage hole late in the cultural period—often results in root mortality.

The presence of mycorrhizae indicates a healthy root system. Inoculation of seedlings with mycorrhizal spores is usually not needed because air-borne spores of native fungi typically inoculate the roots (Barnett and Brissette 1986).

Most commercially available containers have ribs within the cavities to restrict root spiraling. Longleaf seedlings rapidly develop extensive root systems, so spiraling is a potential problem if the ribs are not effective.

BUDS

The presence and color of buds depend on the developmental stage of the seedlings. If seedlings are outplanted in late October or early November, their buds will be more likely to be green than brown, compared to seedlings planted in late December or January. Although planting should not be delayed to obtain better bud development, it is desirable to have buds that have developed to the point that they become brown. Green-budded seedlings may still perform well, but they lack the maturity that provides hardiness and capability to begin early growth in the field.

CONTAINER SIZE

With appropriate cultural techniques, longleaf pine seedlings can be grown in almost any type of container. However, seedlings develop best when density in containers is no more than 50 plants per square foot and container volume is about 6 cubic inches per cavity (Barnett and Brissette 1986). Because longleaf pine seedlings are shade intolerant, close spacings may result in poorly developed plants (Barnett 1989). Seedlings grown in smaller containers may perform well under many conditions, but performance is enhanced by growing plants in larger containers. Container volume is an important consideration because very small containers may result in root systems that are excessively distorted, requiring considerable time to recover after outplanting. A variety of stock types may be suitable for specific sites. But, if stock is contract grown, choice of container type should be agreed upon by the grower and the buyer.

OTHER IMPORTANT ATTRIBUTES

A number of other attributes should be standard for any container production. First, the seedling plug should stay intact when extracted and handled, with no significant loss of potting medium. Second, the root plug should always be moist. Third, no competing weed or insect problems should be evident. The grower should cull seedlings with any such problems during extracting and packing.

Seedlings that begin height growth during the cultural period are usually Sonderegger pines (*Pinus Xsondereggeri* H.H. Chapm.). Sonderegger pine is a naturally occurring hybrid of longleaf and loblolly (*P. taeda* L.) pines (Little 1979) that have some stem elongation in the nursery. These seedlings produce poorly formed trees that are frequently culled because they are less desirable than longleaf pine. Whether Sonderegger seedlings are to be culled or planted should be agreed upon by the grower and buyer of the stock. Normally a very low percentage of nursery seedlings are Sonderegger pine.

CONCLUSIONS

These interim guidelines are designed for producers and users of longleaf pine container stock. They are not meant to exclude any container product. However, we believe growers should be able to attain the seedling specifications listed in the preferred category. Seedlings that meet these guidelines should yield excellent field survival and early height growth. Responses to our questionnaires to growers and users of container stock generally support the criteria. However, seedlings that do not meet the criteria may still perform well on some sites. Refining and improving these guidelines requires evaluating performance of seedlings with a range of physiological and morphological characteristics, planted over a number of years and on a wide range of sites. As additional research data become available, we will revise these guidelines. Some regional tests that are evaluating seedlings grown in a number of container types are underway. We expect these tests and others to help improve guidelines and provide further benefits to longleaf growers and users.

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IRRIGATION AND FERTILIZATION TYPE, RATE, AND FREQUENCY OF APPLICATION

Thomas E. Starkey[1]

ABSTRACT—There is no "cookbook" formula for growing longleaf pine (*Pinus palustris* Mill.). However, some very definite minimum guidelines must be followed to successfully produce an acceptable crop of trees. Irrigation and fertilization are the two most important management practices in the growth of the seedlings. Specific guidelines and checkpoints for both the new nursery manager and the more experienced grower who desires to grow better longleaf are presented in this paper.

INTRODUCTION

The irrigation and fertilization of longleaf pine (*Pinus palustris* Mill.) is not simple or clear-cut. Nursery managers have their own programs that have generally been developed as the result of years of experience. Very seldom will you find any two nurseries that are following the same program. The purpose of the information in this paper is to provide usable information and resources to enable the nursery manager to be successful in growing longleaf pines.

BEFORE WE BEGIN…

Biological growth, whether it is longleaf trees or humans, can be broken down into three phases. The three phases of plant growth in seedling nurseries are:

1. Establishment Phase—covers emergence through cotyledon stage.
2. Rapid Growth Phase—period when growth is at an exponential rate.
3. Hardening Phase—period in which height growth is slowed or stopped.

Knowledge of these phases is important because your approach to irrigation and fertilization will be different in each phase. A well-designed fertilization program will make use of your understanding of these growth phases. For example, less fertilizer in both concentration and frequency are required in both the Establishment and Hardening Phases as compared to the Rapid Growth Phase. Specific recommendations will be presented later in this paper.

Before any irrigation or fertilization program can be initiated, a nursery manager must answer a very important question: "What are the quality standards for my seedlings?" You must know before you begin the season whether you want to grow short and fat seedlings, or tall and thin seedlings, or something in the middle. You must know at the start of the season if your customers have particular seedling quality specifications or if you are going to produce all your seedlings to a standard you have previously determined.

Experience will also show you that not all longleaf seedlots grow at the same rate. It will be necessary to adjust your irrigation and fertilization program to accommodate these differences in rate of growth. If you do not, you will have customers that are dissatisfied with your seedlings, which will be either too tall or too short.

Many nurseries routinely prune longleaf seedlings to obtain a desired height. In my opinion, this is an expensive and unnecessary labor cost that could be reduced or eliminated with a proper fertilization program.

IRRIGATION

The effectiveness of your fertilization program will depend upon your irrigation program. When irrigation is done correctly in terms of frequency and amount, you will obtain maximum benefits from your fertilization program.

HOW DO I IRRIGATE?

Irrigation may be successfully accomplished in many ways. The goal of any system should be to apply water uniformly over the total crop. Irregular irrigation is linked to irregular growth. Irregular growth results in differences in seedling quality. Differences in seedling quality results in dissatisfied customers, which directly translates as lost revenue.

The two methods of irrigation that produce the uniform crops are:

1. Mobile irrigation booms.
2. Fixed overhead sprinklers.

It is very important that frequent visual checks are made of any system to ensure the booms, nozzles, and/or sprinklers are operating properly. Monitoring the amount of water being emitted from the nozzles or sprinklers will tell you if uniform amounts of water are being applied.

There are two other less effective methods of irrigating:

1. Hand watering.
2. Impact head sprinklers

These systems do not produce uniform growth. Impact head sprinklers are especially vulnerable to windy conditions, which can cause irregular growth patterns.

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HOW DO I KNOW WHEN TO IRRIGATE?

There are three commonly used methods of determining when to irrigate:

1. Visual and Tactile—this method requires experience and is very subjective.
2. Container Weight—this method is both time consuming and tedious, especially when large areas must be sampled.
3. Moisture Meters—most moisture meters are designed to be used in soils as opposed to artificial substrates. They are also best used in large containers rather than the small cavities used to grow longleaf.

My personal choice is the Visual and Tactile method. With experience, a manager can be very consistent in evaluating of the need for irrigation. This system also provides a regular opportunity to evaluate the status of root development. Experienced nursery managers can use this system when advising other nurseries as to proper moisture levels. They are not limited by the need for equipment that would be required for the other two methods.

KEY POINTS TO REMEMBER ON IRRIGATION

Each time you irrigate or fertilize, apply sufficient water to wet the entire plug. This amount of water is not fixed throughout the growing season. How much water will depend upon many factors. These factors include: age of the seedlings, time of year and weather conditions (temperature, humidity, wind). Wetting the entire plug to the point that water is dripping out of the bottom of the cavity will prevent the buildup of fertilizer salts.

Low water content in the plug will drastically reduce the effectiveness of your fertilization program. Water is needed in the plug to permit the flow of nutrient ions into the root system.

Improper irrigation can lead to:

1. Poor root growth in the cavity bottom.
2. Potential salt buildup which can injure or kill the seedlings.
3. Stressing the trees so that the growth is halted.

During the heat of the summer, apply sufficient irrigation water to avoid stressing the trees. A common method of hardening off the seedlings at the end of the growing season in preparation for shipping and cold weather is to withhold water. Seedling growth can be slowed during the growing season by water stress.

Between periods of irrigation there needs to be a time in which the cavity is allowed to dry down. Roots will not grow in a saturated plug due to the lack of oxygen. Too much water can be a serious stress factor that can also open the door to fungal problems. The common point that many nursery mangers use is to irrigate when the plug has 50 to 75 percent moisture. How do you determine this point? If you are using the visual and tactile method, it will take experience from looking at many root plugs at different levels of moisture content. If you are using the weighing method, you will need to establish a curve relating weight to available moisture and seedling condition.

Nursery managers must monitor the pH and electrical conductivity (EC) of the medium and irrigation water or substrate leachate. The pH is a measure of the degree of acidity or alkalinity of your medium or irrigation water. The EC is a measure of the salinity (dissolved total salts) of your irrigation water or the substrate leachate. Monitoring should be done on a regular basis throughout the growing season.

The availability of nutrients in the substrate is closely correlated to pH (Figure 1, organic potting media). It is necessary to maintain the medium and irrigation water at a proper pH. If the pH is allowed to deviate, nutrients will no longer be available (even though they are in the medium), and the tree will begin exhibiting symptoms of nutrient deficiencies. One common late-season problem in container nurseries is a yellowing of the new growth of pines. This may be related to an increase in the pH of the medium above 6.5 resulting in iron no longer being available to the tree.

FERTILIZATION

Although the use of slow release fertilizers is a common practice in container nurseries, this method of fertilization will not be discussed here because of the many variations in release rates and formulations. All recommendations are based upon the assumption that only water-soluble fertilizers are used.

Fertilizer mixes are normally expressed as a ratio of nitrogen, phosphorus, and potassium (NPK). For example, a bag of 18-6-12 would contain 18 percent nitrogen; 6 percent phosphorus, expressed as P_2O_5; and 12 percent potassium, expressed as K_2O.

There are two commonly used methods of applying water soluble fertilizer in a container nursery. The first method is by injector. In this method, a concentrate of the fertilizer is mixed and then injected into the water stream before reaching the crop. Some of the commonly used injectors are as follows: Smith®, Dosatron®, Dosamatic® and the MP Proportionator® . Another method is to mix the fertilizer directly in a large stock tank and apply the fertilizer solution directly to the plants.

HOW FREQUENTLY DO I FERTILIZE?

The answer to this question is very simple: “That depends....” Unfortunately, there is no straightforward answer to this question. The frequency of fertilizer applications very much depends upon a number of factors, including:

1. How fast your media dries down—this is a function of the media mix and degree of compaction.
2. How much rainfall you receive.
3. How your seedlings are developing—is the growth on target?

I would recommend that the goal of a new grower be apply fertilizer three times per week, and irrigate on the other days as required. Note that this is a goal; you may not be able to reach this goal some weeks due to rainfall. When there is excessive rainfall, you need to adjust your fertilization

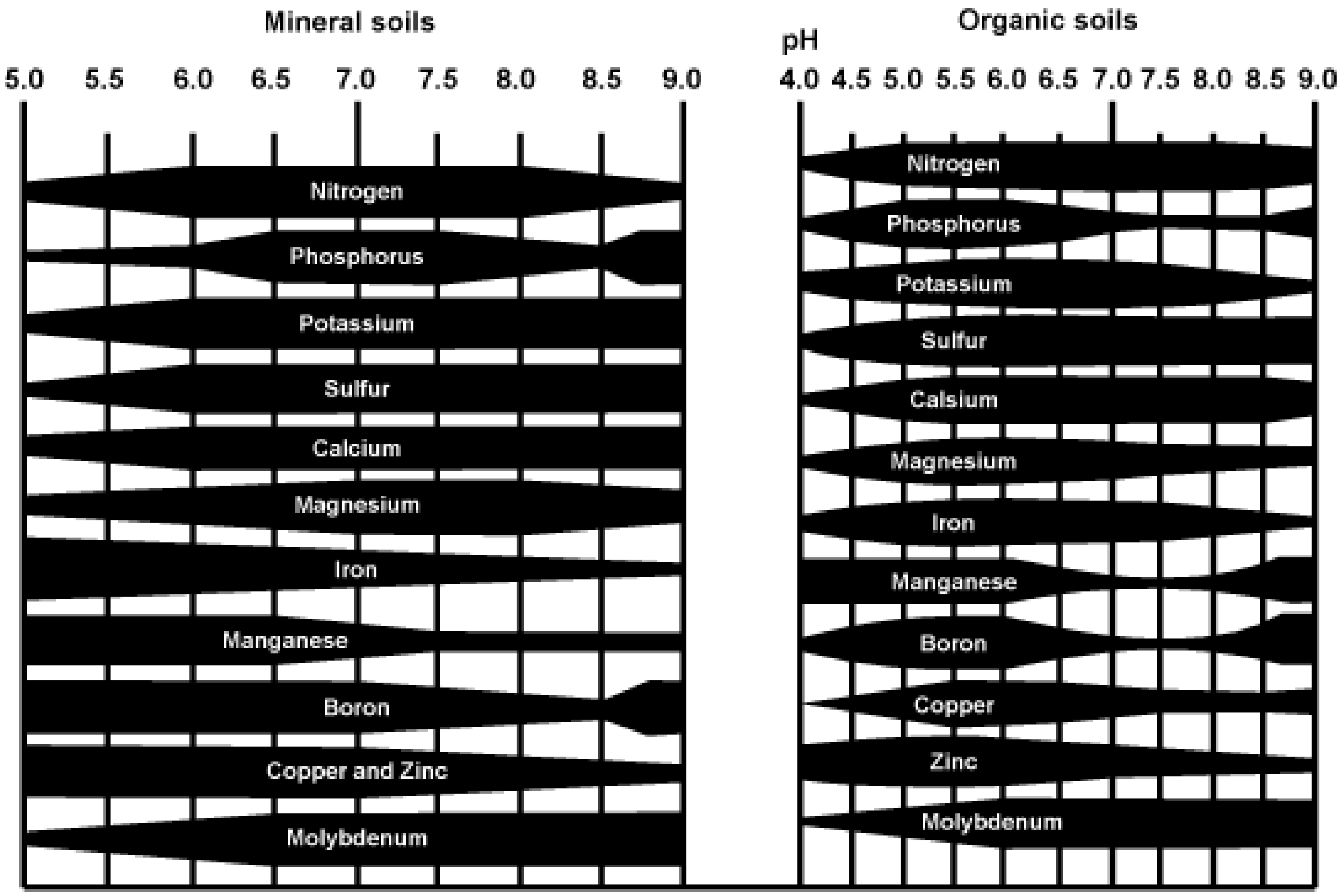

Figure 1—The relative availability (the wider the band, the more available the nutrient) of the various mineral nutrients is different for mineral-based and organic-based soils. From: Kuhns, L.J. 1985. Fertilizing woody ornamentals. University Park, PA: Pennsylvania State University, College of Agriculture. 16 p.

schedule since many of the nutrients may have been leached out of the cavity. The frequency of fertilization also depends upon the specific seedlots you are growing. As mentioned earlier, some seedlots requires less fertilizer than others to reach your seedling quality standards.

TYPE OF FERTILIZER

It is recommended that a new grower begin with a balanced fertilizer such as a 20-20-20 or a 15-15-15. Another very suitable fertilizer to use is one of the “peat special” fertilizers such as “20-10-20 peat-lite”. This formulation is available through many distributors. A nursery grower can produce an excellent crop of trees with these fertilizers. I personally do not feel that the conifer-specific fertilizers on the market are worth the additional cost.

Most established nurseries probably began with any one of these fertilizers but through experience and the necessity to meet certain quality standards, have changed the type of fertilizer they are currently using. There are many options open to the grower who wishes to experiment with a different fertilizer.

TOO MUCH TOO SOON

A common mistake among new growers is to apply too much fertilizer early in the season. These high levels of nutrients reflect improper management, particularly where nitrogen is concerned. High nutrients are wasteful. Often the excess fertilizer is leached out of the cavities. High levels of nitrogen promote a beautiful and lush top at the expense of root system development. The real skill and finesse of a nursery grower is shown by the quality of the root system, not the green stem. High levels of nutrients also inhibit the establishment of mycorrhizae. Mycorrhizae are beneficial in the nursery because they aid in the absorption of nutrients, especially phosphorus and they serve as a barrier against pathogenic fungi. High levels of nutrients early in the season also increase the susceptibility of the plant-to-plant pathogens.

There is a common saying that “if a little is good, more is better”. This is not true when fertilizing your crop (Figure 2). As nutrient levels increase in the plant, an optimum range is reached for the growth response of the crop. Beyond this point, no additional growth is obtained, fertilizer is wasted, and the potential for nutrient toxicity exists.

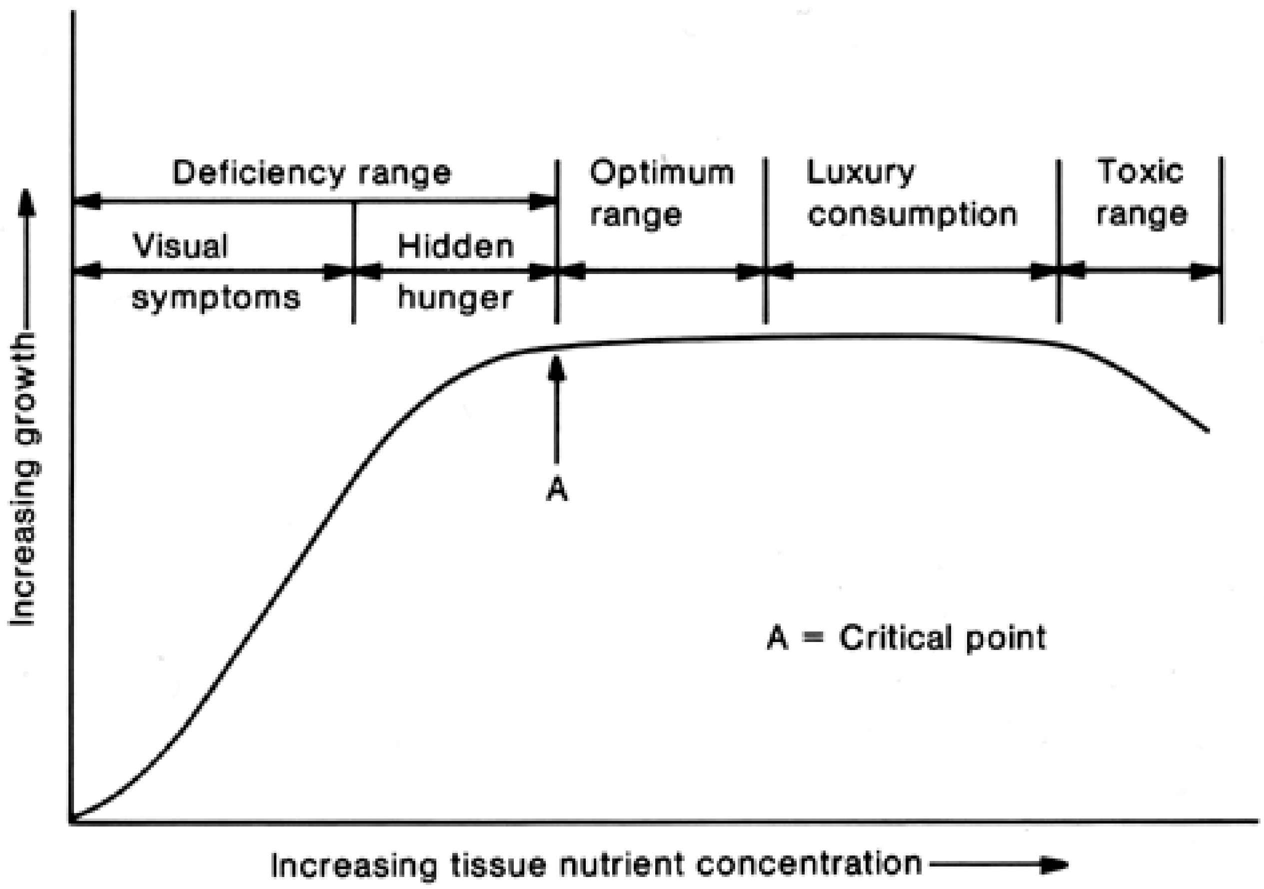

Figure 2—The relationship between seedling growth and seedling tissue nutrient levels follows a characteristic pattern. Point "A" represents the critical level. Beyond this point, increasing nutrient levels do not result in more growth; instead, it can lead to luxury consumption or even toxicity. From: Landis, T.D.; Tinus, R.W.; McDonald, S.E.; Barnett, J.P. 1989. Seedling nutrition and irrigation. Vol. 4. The Container Tree Nursery Manual. Agric. Handbk. 674. Washington, DC: Department of Agriculture. p. 8.

GENERAL GUIDELINES FOR LONGLEAF FERTILIZATION

Listed below are general recommendations for fertilizing longleaf. These recommendations are based upon not using a slow release fertilizer in the media. These suggestions will have to be modified based upon the demands of specific seedlots. Also, remember that a fertilization program must be geared to the specific growth phase of the crop. Here are the general recommendations:

1. Establishment Phase—after germination is completed - 50 ppm for approximately 2 weeks.
2. Rapid Growth Phase—buildup to approximately 200 ppm for 14 to 16 weeks.
3. Hardening Phase—25 to 50 ppm for 4 to 6 weeks.

MONITOR AND RECORD GROWTH

Throughout the growing season, measurements of the height growth, root collar diameter and root growth should be recorded for each seedlot. This information, commonly called "History Plots/Data" or "Life History Data", will provide a valuable foundation for evaluating the growth of future year's crops.

CONCLUSIONS

There are many equally good approaches to producing an excellent crop of longleaf pine seedlings. There are several important points to always be aware of. Know your goal for seedling quality and where you are compared to your goal at any point in time. Monitor and record pH, EC, and growth data on a regular basis. Always be looking for ways to change your fertilization program to make your seedlings a little bit better than your competitor's.

RESOURCE MATERIALS

There are many resource materials available on growing pine trees in containers. The amount of specific information on longleaf pines is much less. The materials listed below are not specific to longleaf pine, but are resources I consider very useful. Over the years, I have narrowed down the number of resources that I consult on a regular basis. Some are available at no charge; others have an associated cost.

The first resource that every nursery manager should have is the USDA Forest Service series on Container Tree Nurseries. These publications cover all aspects of container growing. Do not expect a "cook-book" approach. What you will find is all the necessary fundamental information required to grow container trees. You will need to choose a specific method or technique from those presented. The information is very balanced and complete. The citation is listed below:

Landis, T.D.; Tinus, R.W.; Mcdonald, S.E., Barnett, J.P.
The Container Tree Nursery Manual. Agric. Handb. 674.
Washington, DC: U.S. Department of Agriculture.

As of this publication, there are six volumes in print.

Volume One—Nursery Planning, Development, and Management. 1994. 188 p.

Volume Two—Containers and Growing Media. 1990. 88 p.

Volume Three—Atmospheric Environment. 1992. 145 p.

Volume Four—Seedling Nutrition and Irrigation. 1989. 119 p.

Volume Five—The Biological Component: Nursery Pests and Mycorrhizae. 1989. 171 p.

Volume Six—Seedling Propagation. 1999. 167 p.

For information on these manuals, you may contact Tom D. Landis at the following address:

USDA Forest Service
Cooperative Programs
J.H. Stone Nursery
2606 Old Stage Road
Central Point, OR 97502-1300
TEL: 541-858-6166
FAX: 541-858-6110
E-MAIL: tdlandis@fs.fed.us

A second valuable resource is a book titled "Growing Media for Ornamental Plants". This book covers a wide variety of topics including:

- Growing Media—both the theory and practical aspects behind a good media.
- pH and electrical conductivity.
- Composting.
- Plant Nutrients and Fertilization—also the theory and practical aspects.
- Turf.
- Salinity.
- Irrigation—when and how much.
- Collecting samples for analysis and simple tests that can be performed of growing media.

Although this book emphasizes the horticultural market, it provides a great resource on much of the necessary theory behind growing trees in containers.

The complete citation is:

Handreck, K.A.; Black, N.D. 1994. Growing Media for Ornamental Plants. University of New South Wales Press. Randwick NSW, Australia. 448 p.

The ISBN number is 0 86840 333 4.

It is available in North America through:

ISBS, Inc.
Portland, OR 97213-3644
TEL: 503-287-3093
FAX: 503-280-8832

A third valuable resource is the "Forestry Nursery Notes" (FNN) published by the Forest Service. A subscription is free. This publication has recently undergone a major format change. Technical articles, which were at one time published in FNN, will now be published in "Tree Planter's Notes." The FNN is still an excellent way to keep abreast of publications available on a wide variety of topics.

For information on "Forest Nursery Notes," you may contact Tom D. Landis as described above.

Another publication that is worth obtaining is a real bargain at $10 per year. "Tree Planters' Notes" (TPN) is also published by the Forest Service. There is an on-going effort to improve the quality of this publication. Articles are not solely related to container trees or container nurseries but rather cover a wide variety of topics in this field.

For further information, contact:

George Hernandez
USDA Forest Service Cooperative Forestry
1720 Peachtree Road NW, Suite 811 N
Atlanta, GA 30367
TEL: 404-347-3554
FAX: 404-347-2776
E-MAIL ghernand/8@fs.fed.us

Many nursery managers struggle with calculating parts per million of a fertilizer solution. A handy part per million (ppm) calculator is available for your use on your computer. It will allow for metric or nonmetric unit inputs. You must provide the (1) N-P-K formulation of the fertilizer you are using, (2) the desired parts per million, (3) the injector dilution ratio, and (4) the gallons of water in your stock tank. It will then calculate the amount of fertilizer you must add to your stock tank to obtain your specified ppm of nitrogen (most common), phosphorus, or potassium.

This calculator can be obtained from:

Truett Software Development
2823 Pennsylvania Ave.
Erie, PA 16504
TEL: 814-456-9840.

or from:

Grower Talks Bookshelf
TEL: 888-888-0013
FAX: 888-888-0014

The cost of this program is $29.95 plus shipping.

AN OUTSIDE PERSPECTIVE ON GROWING LONGLEAF PINE— THOUGHTS FROM A NURSERY MANAGER IN THE PACIFIC NORTHWEST

R. Kasten Dumroese[1]

ABSTRACT—Nursery managers in the Pacific Northwest have decades of experience growing pine seedlings in containers. This wealth of information may benefit the South's newly emerging longleaf pine (*Pinus palustris* Mill.) container nursery industry. Container seedling root morphology, seedling nutrition, and integrated pest management (sanitation, chemical control, proper irrigation, disinfestation of seeds and containers) are pertinent to successful production of high-quality seedlings.

INTRODUCTION

For about 30 years in the Pacific Northwest growers have used containers to produce conifer seedlings for reforestation. During the evolution of the industry, growers have tried and modified many techniques to improve seedling quality; some they have discontinued. Three topics from the Pacific Northwest may benefit the South's developing container nursery industry: root morphology, seedling nutrition, and integrated pest management. Although currently a huge demand exists for longleaf pine (*Pinus palustris* Mill.) seedlings because of extensive planned planting projects (Outcalt 2000), progressive growers will strive for high-quality stock to ensure business despite future market fluctuations.

ROOT MORPHOLOGY

Whenever growers of container stock gather, discussions about root morphology of a good root system are abundant. Regardless of definitions, we must meet two criteria: (1) root systems must be sufficient to hold the medium together and withstand shipping, and (2) roots must be able to resume growth after outplanting in order for seedlings to survive and grow on the site. These goals form the business paradigm of root morphology. Poorly developed root systems look bad to our customers, and dead seedlings after planting look even worse. Using hard-sided containers, which are common in our industry, to meet this business paradigm may have risks. One risk that has received much attention is the potential for seedling toppling (Burdett 1978). In most containers, lateral roots contact the cavity wall, are deflected downward until they reach the cavity bottom, and are air-pruned at the drainage hole. After outplanting, these deflected lateral roots resume growth from the bottom of the root plug, often forming a "pivot-point" on which the root plug and seedling top can move, resulting in a toppled tree (Burdett and others 1986).

From this risk a biological paradigm has emerged root growth after outplanting should develop like that of a natural seedling. In forests, seedling lateral roots initiate and grow horizontally close to the soil surface (Baliskey and others 1995; Burdett 1978; Harrington and others 1989), which is typical for longleaf pine as well (Heyward 1933). Growing container seedlings so that lateral root initiation and growth occurs high on the root plug after outplanting provides several advantages. First, with improved mechanical stability seedlings are less prone to lean or blow over in wind (Burdett 1978; Burdett and others 1986). Second, seedlings have roots closer to the forest floor (organic matter) and subsequently nutrients, moisture (Jurgensen and others 1997), and soil-borne mycorrhizal inoculum (Harvey and others 1987a,b). Third, nursery-inoculated mycorrhizae (for example, *Pisolithus tinctorius* on southern pines) show better development and persist longer on seedlings with good lateral root development near the soil surface (Ruehle 1983, 1985).

To meet the objectives of the biological paradigm, containers modifications enhance root growth higher on the plug after planting. Hard plastic containers with slits running the length of the cavities allow air pruning higher on the plug (Ford 1995). Air-pruned lateral roots resume growth after outplanting. Similarly, Jiffypots® (essentially "wall-less" containers) also allow lateral root air-pruning the entire depth of the medium. Containers with copper-coated cavity interiors also prune developing lateral roots of many conifer species, yielding a "bushier," more fibrous root system, lacking long, downward-deflected laterals. Many research projects show the feasibility of enhancing root growth higher on the plug and modifying root systems in containers, particularly pines (Burdett 1978; Burdett and others 1986; Dumroese and Wenny 1997a; McDonald and others 1984; Wenny and Woollen 1989).

Copper-coated container treatments have other benefits in the nursery. Seedlings are generally easier to extract because of the absence of roots along the cavity wall and growing into the styrofoam container. Furthermore, the amount of disease inoculum found on inner walls of reused containers is usually about one-half that of containers without copper (Dumroese and others, in press). Copper products can be applied to containers; factory-coated

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containers are currently more expensive than nontreated containers. For example, in 1999 styrofoam containers (112 cavities and 105 ml (6 in^3 volume)) without copper (Superblock®) cost 0.036 cents per cavity while the same container with copper (Copperblock®) cost 0.048 cents per cavity.

NUTRITION

How much fertilizer is required to grow acceptable longleaf pine seedlings? Growers of longleaf pine should work to find answers to the following five questions:

1. What is the optimum foliar nitrogen (N) concentration for best outplanting performance?
2. What is the optimum N fertilization rate to limit needle production in the nursery and thereby avoid the expense of shearing?
3. Are the answers to questions 1 and 2 compatible?
4. Can increased fertilization with phosphorus (P), potassium (K), and calcium (Ca) enhance root collar diameter growth?
5. Does the grower maintain adequate crop history records to develop an optimum fertilization program for the nursery?

It is well proven that seedling foliar N concentration is related to outplanting survival (Duryea and McClain 1984; van den Driessche 1988). Unfortunately, the optimum N concentration appears to be conditional on what aspect of seedling viability (height, shoot biomass, root biomass, root collar diameter, root growth potential, cold hardiness, survival, or growth) is most important (Bigg and Schalau 1990; Landis and others 1989). For a given species, the fertilizer regime necessary to yield quality seedlings also varies tremendously by nursery because of variables like climate, seed source, water quality, nursery structure, and expertise of the grower (Dumroese and Wenny 1997b). Although obtaining proper foliar N concentration varies at individual nurseries, some aspects of N fertilization appear constant. High N fertilization rates generally decrease the amount of root weight in relation to total seedling biomass in ponderosa pine (*Pinus ponderosa* L.) (Cornett 1982, cited in Landis and others 1989), red pine (*Pinus resinosa* Ait.) (Timmer and Armstrong 1987) and loblolly pine (*Pinus taeda* L.) (Torbert and others 1986). More root weight in relation to total longleaf pine seedling biomass may be the reason needle-clipped seedlings showed higher survival after outplanting over non-clipped seedlings (South 1998). However, evidence exists that nutrient loading (luxury consumption of high N fertilizer in the nursery) enhances pine seedling field performance, especially against aggressive weeds and drought (Timmer and Aidelbaum 1996).

For longleaf pine, a good nutrition program has several concerns. First is controlling N fertilization to reduce problems with needle lodging, clipping, and the potential for growth reductions due to excessive clipping (Barnett and McGilvray 1997; Barnett and McGilvray 2000). Controlling N fertilizer can also increase root weight in relation to total longleaf pine seedling biomass. Another focus is stimulating root collar diameter growth, which is a critical morphological characteristic for seedling growth and survival after outplanting. Large diameter seedlings survive better and grow more vigorously in the field (South and others 1993). Generally, increasing P, K, and Ca in fertilizer solutions discourages shoot growth while encouraging root growth and stem lignification (Landis and others 1989), which should result in larger diameter seedlings.

It is important to maintain good nursery records, especially for cultural practices. Detailed records allow growers to duplicate successful crops, adjust fertilizer applications to current crops in order to achieve desired growth, and make plans to avoid problems in future crops (Nelson 1991). Landis and others (1994) present a fine review on data collection and its benefits to growers. Their treatise should be required reading for anyone growing forest seedlings.

INTEGRATED PEST MANAGEMENT

At the University of Idaho Forest Research Nursery we have spent considerable time focusing on disease control and integrated pest management (IPM). Pest management really boils down to proper irrigation and good sanitation.

Proper Irrigation

Watering too often encourages development of nearly all root rot diseases in the Pacific Northwest caused by fungi in the genera *Fusarium*, *Pythium*, *Phytophthora*, and *Cylindrocarpon*. Excessive irrigation also fosters spread of shoot diseases by fungi in the genera *Botrytis*, *Rhizoctonia*, and *Sirococcus* either because foliage remains wet too long or because spores are spread by splashing irrigation water. Similarly, water management for disease control is paramount in longleaf pine container nurseries (McRae and Starkey 1996).

Three methods help determine when irrigation is needed: visual-tactile, container or block weight, and pressure chamber. Generally nurseries only use the first two methods (Landis and others 1989). The easiest, least-expensive method is visual-tactile. Essentially, growers look at and feel the medium to see if irrigation is necessary. Some advantages of this method include: (1) by monitoring root development growers notice diseases; (2) they need no special equipment; and (3) they develop “a feel” for their crop. With regular, close inspection, they enhance the art of growing seedlings. A few disadvantages exist because it is difficult to: (1) check medium around roots until there is sufficient root development to extract a plug; (2) define to employees when irrigation is necessary; and (3) maintain objectivity concerning optimum times to irrigate.

Container weight change can be a useful method to determine irrigation need (Landis and others 1989). The process is straightforward and has advantages and disadvantages (table 1). After the medium is saturated, containers are weighed on an accurate scale to determine saturated container weight. Thereafter, most of the change of container weight is due to loss of water through seedling transpiration. At the Research Nursery, we irrigate when containers weigh 85 percent of their saturated container weight during the seedling initiation phase, 80 percent during the rapid growth phase, and 70 percent during the hardening phase (table 2).

Table 1—Advantages and disadvantages to using container weights to determine irrigation need

Advantages	Disadvantages
Easily done.	An accurate scale is required.
Easily repeated week to week, year to year.	Growers may stop looking at their crop (as is the case with visual-tactile).
Allows grower to objectively manipulate moisture available to seedlings, particularly important during hardening.	
Allows employees unfamiliar with practices to apply water when seedlings require it.	

Table 2—An example record of container weights assuming a saturated container weight of 11.8 kg[a], and that seedlings will be watered when container weight reaches 85% of the saturated container weight (11.8 kg x 0.85 = 10kg)[b]

Container weights	July 21	July 22	July 23	July 24	July 25	July 26
Saturated weight (kg)	11.8	11.8	11.8	11.8	11.8	11.8
Actual weight (kg)	10.0	11.3	10.6	10.0	11.1	9.8
Percentages	85%	96%	90%	85%	94%	83%
Need to water?	Yes	No	No	Yes	No	Yes

[a] kg = 2.2 lb
[b] Source: Dumroese and others (1998)

Growers can determine how long to irrigate by reweighing containers—stopping irrigation once they achieve saturated container weight. Saturated container weights change with crop age, so growers should determine a new saturated weight about once every 6 weeks (Dumroese and others 1998). Over time, growers can model the amount of irrigation water necessary to saturate containers at different crop stages.

Good Sanitation

Good sanitation, key to any nursery pest-management program, begins at cone collection. Harvesting high-quality cones and treating them correctly is the best start (Barnett and Pesacreta 1993). Because longleaf pine seedling diseases can reside on some seedlots and not others (Fraedrich 1996), growers should avoid having seedlots come in contact with each other (Neumann and others 1997b). One important seedborne pathogen is *Fusarium subglutinans* (Wollenweb. & Reinking) Nelson, Toussoun & Marasas f. sp. pini, which can cause significant mortality of longleaf pine seedlings in both bareroot and container nurseries (Carey and Kelley 1994; Fraedrich and Dwinell 1997).

Growers can reduce seedborne disease inoculum by soaking seeds in bleach, hydrogen peroxide, benomyl, or running water. At the Forest Research Nursery, a bleach treatment has worked well for pines, consisting of soaking seeds 10 min in a solution of 2 parts bleach (5.25 percent sodium hypochlorite) to 3 parts water, followed by a thorough rinse with clean water. (Dumroese and others 1988; Wenny and Dumroese 1987). In the South and particularly on longleaf pine, soaking seeds in hydrogen peroxide has yielded excellent germination results. Hydrogen peroxide is commercially available in two forms: 3 percent and 30 percent. The 3-percent hydrogen peroxide is less caustic and available in many stores, whereas the 30-percent grade must be ordered from chemical companies. Although a 4-h soak in 3-percent hydrogen peroxide effectively removed *Fusarium* inoculum from coastal Douglas-fir (*Pseudotsuga menziesii* var. *menziesii* [Mirb.] Franco) seeds without reducing germination (Neumann and others 1997a), longleaf pine seeds appear to perform better after a longer soak in a more concentrated solution. A 55-min soak in 30-percent hydrogen peroxide at 24 °C (75 °F) followed by a triple-rinse in clean water (Barnett 1976; Barnett and McGilvray 1997) is very effective in removing seedborne *F. subglutinans* (Fraedrich 1996). As a bonus, hydrogen peroxide treatments can also improve germination of low viability seedlots (Barnett 1976). Barnett and others (1999) found that a 10-min benomyl 50 WP drench (0.5 percent solution; 227 g per 45 L) was effective in improving germination of low- and medium-quality longleaf seedlots. When compared to the 55-min soak in 30-percent hydrogen peroxide, the benomyl treatment was as effective, less expensive, and safer (Barnett and others 1999). Soaking seeds in a container through which water flows reduces fungal inoculum (James 1987; James and Genz 1981). The simplest way to accomplish the running water soak is to place a hose in the bottom of the container used to soak seeds and allow water to run up and over the container top. To avoid cross contamination, growers should treat seedlots separately and thoroughly clean the soaking container with hot water and soap following treatment (Neumann and others 1997b).

During sowing, growers should wash hands between different seed sources. If diseased seedlings appear in the crop, growers should remove them and either burn, bury, or discard them off-site to reduce inoculum (James and others 1990). Rolling or moving bench systems can greatly facilitate this operation. In greenhouses, weeds, soil or gravel underneath seedling crops contribute to disease expression; greenhouses with concrete floors have less disease problems (James and others 1988b). Weeds under tables may harbor pathogens similar to those that attack conifer seedlings (James and others 1987). When checking a crop to see if irrigation is necessary or if pests are present, growers can carry a bucket to collect and discard diseased seedlings. Reducing the inoculum load within a crop by vigorous culling of diseased seedlings will reduce the risk of that pathogen spreading, as well as reduce available substrate for secondary fungi, some of which also elicit disease (Landis and others 1990).

Many growers are often lulled into complacent sanitation and sloppy irrigation practices believing that they can cure or prevent problems with pesticides. But why hassle with chemical applications and the EPA Worker Protection Standard if you don't have to? Reducing pesticide applications reduces production costs, which in turn increases profits. Some chemical applications are prudent and unavoidable. A good chemical program involves rotating pesticides, especially fungicides, to avoid having diseases develop resistance to chemicals (Dekker 1976; Delp 1980). At least three fungicides should be in rotation, and fungicides should be from different chemical families, not just different chemicals or trade names. For example, if *Rhizoctonia* is the problem disease, a rotation of Cleary's 3336® (thiophanate-methyl), Bayleton® (triademefon), and Bravo® (chlorothalonil) would work well because all three products are in different families (benzimidazole, triazoles, and aromatic, respectively). A rotation of Cleary's, Bayleton, and Benlate® (benomyl) is less desirable because both Cleary's and Benlate are benzimidazoles.

After harvesting the crop, a thorough cleaning of the growing area between crops is an important step in any IPM program (James and others 1990). Proper container cleaning is also a prudent sanitation step. In one of our studies, we found that using pressurized hot water to wash containers, alone or in combination with bleach, allowed inoculum of potential pathogens to carry-over from crop to crop on both hard plastic and Styrofoam containers (James and others 1988a). This carry-over of disease inoculum can increase disease incidence (and seedling mortality) or decrease overall seedling growth overtime (fig. 1). Although figure 1 only shows a comparison of height growth, the same trend was evident for other morphological characteristics (root collar diameter, root weight, shoot weight, root volume) and merchantable seedlings produced per container (Dumroese and others, in press). Despite the testing of a wide-variety of chemicals (Peterson 1990, 1991), we have found a quick soak in hot water to be the most efficacious in removing disease inoculum from reused containers. In the interior Pacific Northwest, growers use a variety of large soak tanks (stock tanks, custom-built tanks) and methods for heating water (heaters on power washers, boilers) to accomplish the task. The key is water temperature and soak duration. For hard-sided plastic containers, a 15-sec soak in 82 °C (180 °F) water is very effective. Although some recommend a 10-sec (Peterson 1991) or 3-min soak (Sturrock and Dennis 1988) for Styrofoam containers, we have found a 1-min soak in 82 °C (180 °F) works well, but at 71 °C (160 °F) the duration must be increased to at least 3 min. We do not soak containers when temperatures fall below 70 °C (160 °F) because inoculum is not destroyed, or when temperatures are above 85 °C (185 °F) because Styrofoam containers begin to distort. A mechanized system where containers are on a conveyor and pass through hot water would be ideal for very large nurseries. However, several Pacific Northwest nurseries, including one growing 12 million seedlings, find that a system where containers are hand loaded into cages for submersion is cost effective.

It is only natural for new growers to err on the side of caution when dealing with diseases. I challenge longleaf growers, as they develop their art and science of growing seedlings, to reduce both the volume and frequency of pesticide applications. At the Research Nursery our focus on an IPM plan, stressing sanitation, proper irrigation, and container cleaning, drastically reduces the amount of pesticides (fig. 2). Reducing pesticides saves money, eases compliance with the EPA's Worker Protection Standard, lowers neighbors' concerns about inadvertent pesticide drift or groundwater contamination, and provides a market tool (healthy seedlings).

CONCLUSIONS

Growers of longleaf pine face an exciting and challenging future. Progressive growers that develop their "art of growing seedlings" along with proper attention to record keeping of cultural practices will be successful despite changing markets. Developing some criteria for "optimum" longleaf pine seedlings for root morphology, foliar N concentration, root collar diameter, and production costs should be a priority. All desirable seedling characteristics should be based on field results after outplanting rather than the aesthetic quality of the nursery crop. Proper irrigation and good sanitation will help reduce production costs and ensure production of high quality seedlings.

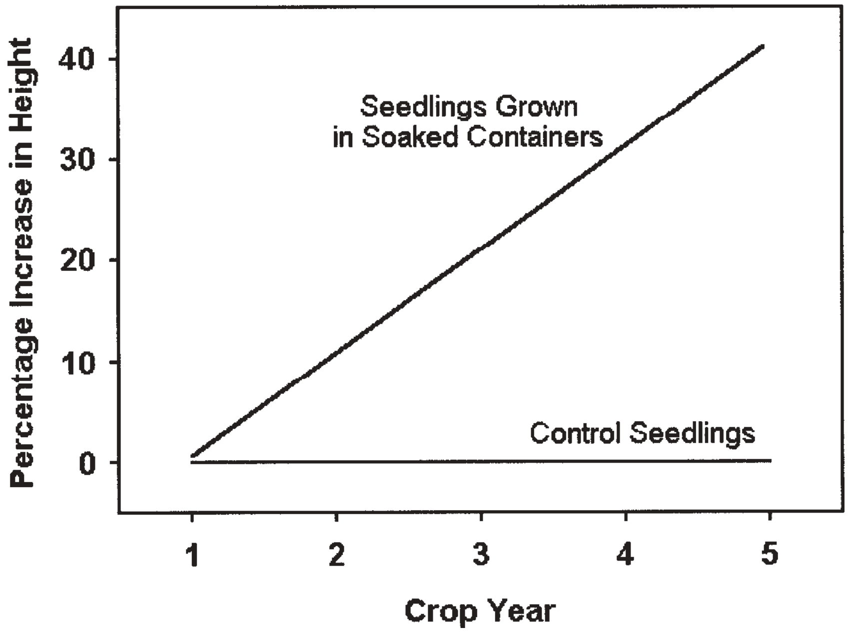

Figure 1—Relative heights of Douglas-fir seedlings grown in reused Styrofoam containers. At the end of the second growing season, seedlings grown in control containers (not dipped in hot water before the second growing season) were 10 percent shorter (heights normalized to 100 percent) than those grown in reused containers dipped in hot water (82 °C [180 °F] for 1 min). After three growing seasons, seedlings grown in reused, treated containers were nearly 25 percent taller than those grown in nondipped containers.

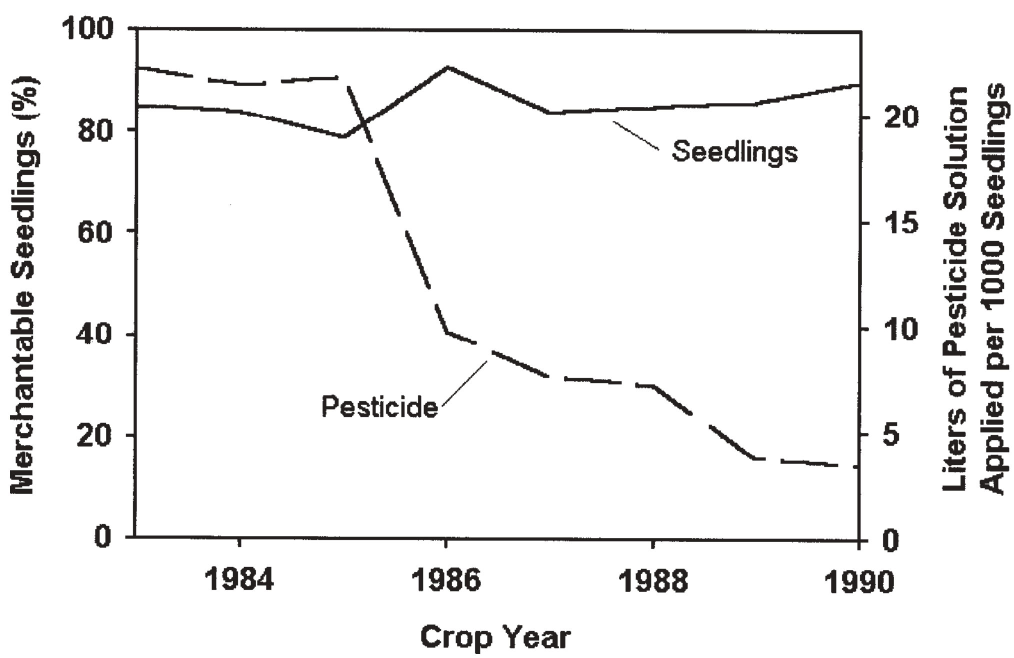

Figure 2—In 1986, the University of Idaho implemented an integrated pest management (IPM) plan that focused on sanitation, proper irrigation timing and amounts, and fewer preventative fungicide applications. The result was a significant drop in the amount of applied pesticide solution while the percentage of deliverable seedlings remained constant (1 L = 0.26 gal). Source: Dumroese and others (1990).

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PEST CONTROL FOR CONTAINER-GROWN LONGLEAF PINE

Scott Enebak and Bill Carey[1]

ABSTRACT—Several insect, weed, and disease pests are discussed that have been observed affecting container-grown longleaf pine (*Pinus palustris* Mill.) seedlings. The available tools to minimize the effects of these pests are limited to a few select insecticides, herbicides, and fungicides. Extreme care should be taken to ensure that the chemical chosen is used within the recommended guidelines and used with proper equipment. Accurate identification of the pest is important to ensure that the correct remedy is chosen. When growing longleaf pine seedlings in containers, pest prevention is cheaper than crisis intervention. Care should be taken to use the best available clean seed and potting media, to clean containers between crops, and to prevent stress by using the right amount of irrigation water. A list of pesticides is given to aid the grower in selecting the proper tool for pest problems.

INTRODUCTION AND CAUTIONS

If you have experience growing longleaf pine (*Pinus palustris* Mill.) seedlings in containers you may find it difficult to believe that containerization is supposed to reduce pest problems. Actually, it just changes the set of pest problems, compared to bareroot nurseries, and increases their importance by increasing the per-unit crop value. In integrated pest management (IPM), pesticides should be applied only at or above the economic threshold (ET). That is, at the point where the value of damage is just greater than the cost of the pest control. With container seedlings costing four times as much as bareroot seedlings, the ET is reduced to a fourth.

Pest control covers protecting your crop from three categories of pests: fungi, insects, and weeds. The tools for this are, not surprisingly, fungicides, insecticides, and herbicides. Each of these "tools" (pesticide categories) come with a different set of cautions associated with the consequences of making an application mistake. The wrong fungicide will not stop the disease. Careless or incorrect application of an insecticide is dangerous to the applicator and to the environment. The wrong rate or careless application of any herbicide can severely damage longleaf seedlings.

The diseases and insects presented here are those the authors have found associated with container-grown longleaf pine seedlings (table 1, 2). The herbicides shown are a shortened list of ones used in the bareroot nursery industry (table 3). We suspect the level of pesticide experience differs widely among producers of container-grown longleaf pine seedlings. Remember that workers and pesticide handlers must be trained under Worker Protection Safety (WPS) regulations every 5 years. Agriculture is not complying well with WPS regulations (<50 percent compliance), and a push for greater enforcement seems to be in the works. If caught in noncompliance you may receive a substantial fine. Contact your local county extension office for assistance in getting yourself or your workers the necessary training. Everyone must be properly trained and licensed by their State before obtaining or using most, if not all, of the products mentioned.

DISEASES

Fusarium Spp.

One of the more troublesome fungal organisms in container nurseries is the genus *Fusarium*. At least four species of the genus are generally considered opportunistic pathogens. They take advantage of stressed or weakened seedlings. The most common of these fungi are *Fusarium oxysporum*, *F. solani*, *F. piliferatum* and *F. subglutinans*. Their affects on longleaf production appear to the nursery manager as (1) poor germination, (2) damping-off, (3) root rot, (4) late-season root and crown rot, and even (5) seedling mortality after outplanting. While these fungi can be spread by wind and rain, the most common entry point into the nursery is with seed. Improperly collected and processed cones and cones from seed orchards may have a greater incidence of these fungi. Typically, mortality from these fungi are scattered or random throughout the nursery, but the percentage of seedlings infected often varies by seedlot. When environmental conditions favor spread, serious infestations may spread between container cells. The State of North Carolina now has a special local needs (24-C) registration for a Benlate® seed treatment that has improved germination and cavity fill in preliminary tests. Additional 24-C registrations are desirable in States that produce many container-grown longleaf seedlings. Seedlots suspected of extensive contamination can be treated with surface disinfectants such as hydrogen peroxide (H_2O_2), which has improved performance in some tests. Evaluations to register new fungicides to improve longleaf seed germination are in progress.

Rhizoctonia Solani

Probably the second most destructive fungus among container-grown longleaf is *Rhizoctonia solani*. This fungus is particularly serious on longleaf because of the seedlings

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Table 1—Chemicals registered for use in controlling diseases in longleaf

Agent	LD_{50}	Used	Fungus	Rate(lbs/acre)[a]
Bayleton Triadimefon	363	Foliar	Rusts	0.25–0.5
Captan	9,000	Seed Foliar	Damping-off *Botrytis*	0.5–5.0 ai 0.06–0.6/100 1bs seed
Thiram Gustafson-42S	780	Seed	Damping-off Birds, rats	2 gal = 10 oz Latex/100 lbs seed
PCNB Terraclor	12,000	Soil Seed	*Rhizoctonia*	5–200 ai or 0.5–0.75/bu
Chlorothanil Bravo	10,000	Foliar	*Anthracnose* *Botrytis*, etc.	0.75–1.0 ai
Iprodione Chipco-26019	3,500	Contact Foliar	*Botrytis* *Alternaria*	0.25–2.0 ai
Fosetyl-AL Aliete	2,000	Foliar Systemic	Phycomycetes *Rhizoctonia*	1.5–2.0 ai
Thiophanate Cleary-3336-F	15,000	Soil Foliar	*Fusarium* *Botrytis,* etc.	0.12 ai
Thiophanate methyl + terrazole = Banrot	1,070	Soil	Phycomycetes	0.38 A *Fusarium* *Rhizoctonia*
Metalaxyl Subdue	669	Soil Foliar	Phycomycetes	0.6 ai

LD_{50} rates of application are given for comparative references between products and not as guided to safety or application and use rates. For application rates consult product label which must be on site at use.

stature. Rhizoctonia may be in planting media, and when this gets on the buds of longleaf seedlings, which are just above ground level, the fungus can infect both bud and needle tissue. After infection, the fungus causes a rapid death of the bud and needles and is capable of spreading rapidly through the container sets. Symptoms first appear as a water-soaked lesion that quickly turns yellow, then brown, and then darken as the bud and needles decay. The tightly packed nature of longleaf seedlings in containers and irrigation systems common in nurseries favor the growth and spread of this fungus. Circular areas of brown, dead, and dying seedlings are a good indication of *Rhizoctonia* infection. Seedlings symptomatic of this disease should be placed away from the general population to reduce spread. This fungus can remain in soil particles left in containers from year to year in resistant structures called sclerotia. Sanitation is important to minimize carryover. Other container crops have benefited by the disinfestation of containers. This disease is also a problem in bareroot nurseries, and recent tests in South Carolina indicate that Chipco 26019® was effective at reducing disease incidence among bareroot seedlings.

Pythium Spp. and *Phytophthora* Spp.

Two other fungi that may be responsible for mortality in longleaf are *Pythium* and *Phytophthora*. These, too, are opportunistic pathogens that take advantage of stressed seedlings, especially seedlings that are over-watered. These fungi are considered water molds, as they move through the soil/water using a whip-like tail. Mortality by *Pythium* and *Phytophthora* appears as either damping-off or root rot early in the growing season and typically is scattered among the sets. As the seedling matures and becomes lignified, these pathogens are not a problem. Many, perhaps most, growers of container longleaf alternate some schedule of treatments with Subdue®, Cleary's®, and/or Aliete® to prevent damage by these water molds. Whether this works or if problems would be rare anyway is hard to tell. We have noticed that some plant diagnostic clinics find one or both of these organisms in every sample they receive. That doesn't necessarily indicate they were the problem.

Table 2—Chemicals registered for controlling insects in longleaf pine

Agent	LD_{50}[a]	Family	Used	Insects	Rate/acre
Chloropyrifos Dursban, Lorsban	96	OP[b]	Contact	Corn borer Stomach	0.1–5 A lb
Esfenvalerate Assana	325	Perethroid	Contact Stomach	Lygus	0.1–1 lb ai
Pernethrin Pounce	430	Perethroid	Residual Activity	Lepidoptera Weevils	0.05– 0.2 lb ai
Diazinon Spectracide	300	OP	Long Residual	Many	0.25–2 A lbs
Malathion	1,375	OP	Foliage	Many and mites	0.5–3 A lbs
Bifenthrin Talstar Firebrand?	54	Perethroid	Contact Stomach	Fire ants	

[a] LD_{50} and rates of application are given for comparative references between products and not as a guide to safety or application use rates.
[b] The EPA may soon ban all OP (organophosphates)

Table 3—Herbicides registered or probably registered for growing container longleaf

Product	Crop plant	Container	PPE[a]	REI	Rate/acre[b]
Goal	Conifers	Yes	1,3,4,5	24	Pre 1–2 pts Post 1–2 pts
Cobra[c]	*P. palustris*	Yes	1,2,3,4,5	12	Pre 0.5–1 pt Post 0.04–1 pt
Vantage	*P. palustris*	(Bedding plants)	1,2,3	12	Post 2.25–3.75 pts
Fusilade[d]	Conifers	(Nursery beds)	1,2,4	12	Post 1–2 pts

[a] PPE code = 1 shoes + socks, 2 long sleeve shirt, 3 coveralls, 4 gloves, 5 eye protection.
[b] Rates of application are given for comparative reference between products and not as guides to safety or application use rates. For application rates consult product label which must be on site at use.
[c] In general, pine are more tolerant to Cobra that to Goal.
[d] Fusilade should probably be used without recommended COC or NIS.

OTHER DISEASES

Two other diseases that can infect longleaf pine at the nursery but will only be noticed after outplanting are pine needle rust and brown spot needle blight.

Needle Rust

Pine needle rust is caused by fungi in the genus *Coleosporium*. This disease may cause inconspicuous spots on the foliage at the nursery in the fall that may appear similar to brown spot. The next spring, after outplanting, small, yellow-white blisters form on the needles. These blisters are full of white to yellow aeciospores that do not infect pine, but rather infect other rust hosts, which are several common "weed" species such as goldenrod and morning-glory. Although fungicidal control would seldom be justified, Bayleton® would work. Even with spectacular needle infections, pine seedlings will normally survive without any problems. If seedling appearance is important to the customer, then locating the nursery away from the alternate host, or elimination via mowing or herbicides, is the best method to control this disease.

Brown Spot

Brown spot needle blight is the last of the common diseases that may occur in the production of longleaf pine. This disease, caused by the fungus *Mycosphaerella dearnessii*, occurs throughout the Southeastern United States. Other pine species seldom get brown spot needle blight, and the disease is economically important only to longleaf pine. The fungus is spread via wind and rain splash of spores, and infection occurs throughout the year. The disease first appears as small gray spots on the foliage of longleaf, which become yellow, then brown, as the infection progresses. Each infection site has three distinct zones: green, yellow, and brown; multiple infections eventually coalesce on the needle giving it a mottled appearance. Infected seedlings rarely die, but severely infected trees will not commence height growth and may be defoliated and lose vigor to such a point that other agents kill it after outplanting. If experience shows that fungicidal control is regularly needed, Bravo® or Maneb® will prevent infection when prophylactically applied. This disease was once considered a major problem to reestablishment of longleaf pine in some regions of the South. The production of more vigorous seedlings and site treatments that shorten the "grass stage" of longleaf seedling development have greatly reduced the impact of this disease outside the nursery. Prevention and sanitation is the best method to control this disease.

INSECTS

Fire Ants, Tip Moth, Pine Webworm, Saw Flies, Fungus Gnats

There are few, if any, insect pests in container-grown longleaf that warrant prophylactic treatments (Table 2). Instead, these pests are probably all controlled adequately by appropriate measures after the insects are discovered in the early stages of an infestation. This may not be true at all locations, and local experience may indicate exceptions with time. The types of actions required will differ depending on the quantity of seedlings being produced. For example, typical infestations of saw flies and/or pine webworms can be controlled through physical "squishing" at all but the largest container nurseries. Tip moths once caused a significant problem in bareroot longleaf, and they have the potential to damage container seedlings. If experience determined that under your conditions as little as 3 or 4 percent of your seedlings were destroyed by tip moths, some preventative treatment would probably be justifiable. Fire ants are certainly not amenable to squishing, and these are a predictable occurrence at some locations. In addition, certain quarantine restrictions can be triggered if fire ants are detected in a nursery or a shipment of seedlings. Fungus gnats have been suspected of causing problems among longleaf seedlings at some nurseries. Although physically capable of damaging fine roots, the gnats usually become noticeably abundant only when potting media is kept wetter than is optimal for the seedlings. It is my opinion that the damage sometimes attributed to these pests is largely due to disease organisms and poor root development caused by too much water.

WEEDS

Northern producers report that weeds are not a problem in their containers. It takes little investigation to determine that the South is different. However, the "science" of weed control in container production for southern pines is still in its very early stages, and there is nothing like the fairly standard protocol that exists for bareroot nurseries. Hand weeding is an option in small operations and some fairly large productions are still "crisis oriented" with respect to weeding or herbicide application. This will have to change where many seedlings are produced, and small productions should benefit economically if preventative measures were employed. Small weeds are controlled by much lower rates of herbicides than are larger weeds.

The information presented here was obtained from a telephone survey and may be a starting point for a weed control program appropriate for some nurseries (Table 3). There is a very short list of herbicides that should have selective activity, and the use of any of these should be initiated with great caution. One thing that makes a control program difficult to formulate is that both the weeds and possibly the activity of pre-emergent herbicides will differ with peat from different sources. The only "weed" species mentioned by several nurserymen was willow, and that is probably just a function of wind-blown seeds. Some nurserymen believe that weed seed comes in some of the media they purchase.

Of many sick and dead seedlings observed by the authors, in many cases, herbicide damage is the cause of the problem, even though disease is usually the first culprit suspected. This paper is not to be considered to provide an endorsement of safety or efficacy of any pesticide discussed or listed. The tables are provided to help reduce the number of herbicides you might otherwise have to look through if you have limited experience in this area. Always when using an herbicide for the first time apply to a test plot of no more than you are prepared to loose. Reactions can change from year to year. Soil or planting media affect the way plants respond to herbicides. Any kind of stress will change the response of plants. You must have an appropriate label on site to use a pesticide and you really should read it and follow directions.

WATER QUALITY IN THE PRODUCTION OF CONTAINERIZED LONGLEAF PINE SEEDLINGS

David J. Moorhead and John M. Ruter[1]

INTRODUCTION

The consistent production of quality container grown seedlings requires that key production variables be identified and controlled; otherwise, quality and the percentage of marketable plants will be erratic (Garber and Ruter 1993a). Additionally, production times and costs may increase unless production variables are monitored and managed throughout the production cycle.

Accessing and maintaining water quality is essential for quality seedling production. As a prime factor influencing plant growth: water is the major plant constituent making up 80 to 90 percent of plant fresh weight; it serves as solvent, providing nutrient transport within the plant; it is a biochemical reactant for plant processes; and it is requisite for maintenance of cell turgor to promote cell expansion and growth (Kramer 1983).

Water is the principle agent limiting plant growth, and thus frequent irrigation is necessary to maintain optimal growth. Water is also used as a mixing agent or carrier for the application of fungicides, fertilizers and insecticides used in container seedling production.

REVIEW

Two excellent reviews of water quality issues specific to the production of containerized tree seedlings have been prepared by Landis (1989), and Tinus and McDonald (1979) that the reader is referred to for a detailed discussion of greenhouse/container water quality. This paper will highlight selected irrigation water quality issues pertinent to longleaf pine container seedling production. Two factors are of primary importance when evaluating irrigation water quality: the concentration and nature of dissolved salts and the presence of pathogens, weed seeds, algae, and pesticide contamination (Landis 1989). The pH of the irrigation water and its interactions with the growing substrate and mineral nutrition is a third important factor.

WATER-QUALITY ISSUES

Sources

Water source can greatly influence quality. Generally, irrigation sources available to most container operations will be from one of these categories:

€ Surface—ponds, streams

- Ground water wells
- Municipal—treated well or surface water.

Surface water sources can provide high-quality water supplies, but they must be carefully monitored. Suspended solids (such as sand, silt, and organic matter) may damage or clog irrigation systems. Weed seeds, algae and pathogens (such as fungi and nematodes from agricultural operations) in the watershed can pose serious production problems. Filtration can remove coarse suspended solids, but removal of silt, fine seeds, spores, etc., is difficult and expensive. Pesticides contamination, particularly from herbicides, or other chemical contaminants (such as fertilizers introduced from adjacent agricultural operations) can be detrimental to seedling production and may be difficult to remove.

Ground water wells generally provide water that has very little suspended matter. Levels of dissolved salts (total and individual ions) and pH must be monitored (table 1). Water quality will vary depending on location. In southern Georgia, most wells deliver alkaline (high pH) water, whereas those in central Georgia are generally acidic. Growers near coastal areas need to be aware of salt-water intrusion.

Table 1—Irrigation water quality target values

Factor	Target value
pH	5.4–7.0
Conductivity	0.2–2.0 dS/m
Bicarbonate	<100 ppm or 2 meq/L
Alkalinity or TC	<100 ppm VaCO3 or <2 meq/L
Hardness	<150 ppm or <3.0 meq/L
Sodium	<69 ppm or 3.0 meq/L
Chloride	<71 ppm or 2.0 meq/L
Nitrate-N	<10 ppm
Ammonium-N	<10 ppm
Phosphorus	<1 ppm
Potassium	<10 ppm
Calcium	<60 ppm
Magnesium	<25 ppm
Iron	<4 ppm
Sulfur	<24 ppm
Manganese	<2 ppm
Zinc	<0.3 ppm
Copper	<0.2 mmp
Boron	<0.5 ppm
Molybdenum	<0.1 ppm
Aluminum	<0.5 ppm
Fluorine	<1 ppm

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Municipal water supplies typically will be free of suspended matter as well. Potable water supplies still require monitoring of dissolved salts and pH (table 1).

Dissolved Salts

Salts dissolved in water release ions, or charged particles. A fertilizer salt such as KNO_3 releases one positively charged cation (K^+) and one negatively charged anion ($N03^-$). Both K^+ and $N03^-$ are plant nutrients. The total concentration of the salt in solution determines whether it is beneficial to the plant as a nutrient source or if concentrations are high enough to be harmful. Other dissolved salts can have toxic ions that damage or kill plants. Sodium chloride (NaCl) contains two ions (Na^+ and Cl^-) that will harm plant tissue even at low concentrations in water (Landis 1989).

The ions dissolved in water conduct electricity and the degree of salinity in water is expressed by electrical conductivity (EC). The greater the salt concentration, the higher the EC. Electrical conductivity can be rapidly determined using relatively inexpensive portable conductivity meters. These meters, which often include a pH meter, permit rapid testing of EC in irrigation water and leachates from container substrates. This is useful in monitoring the nutrient status of the water and container substrate throughout the growing cycle (Garber and Ruter 1993b, Ruter and Garber 1993). Monitoring of salt levels through EC is an important quality control measure as salinity can affect seedling growth and plant quality. Fuller and Haldermann (1975) and Landis (1989) discuss the following influences that salinity has on container seedling production:

- Availability of water (decreased by high salt concentrations)
- Presence of toxic ions
- Availability of nutrients
- Staining of foliage

The salinity of the water applied to the seedling growing substrate can influence the availability of water to the plant. The salt in solution creates a negative osmotic effect or potential in the substrate solution. This negative potential reduces the water availability to the plant. This becomes a serious problem when irrigation water with a high EC or dissolved nutrients are applied to dry media. Reduction in water uptake can be detrimental during germination (Landis 1989). Conifer seedlings are extremely sensitive to salinity damage and will exhibit reduced growth rates and foliar tip burn.

Direct toxicity of specific ions can induce growth losses and mortality. Sodium, chloride, and boron are ions that are directly toxic to seedlings. When present in high concentrations, metal ions such as manganese and zinc pose toxicity problems as well.

Nutrient availability in the media can be influenced by the excess of certain ions (Landis 1989). High levels of calcium and magnesium can induce nutrient imbalances in the growing substrate and retard plant uptake. Calcium levels in excess of 100 ppm in the irrigation water can lead to buildup of Ca^{2+} in the growing substrate that eventually causes a magnesium deficiency. A ratio of less than five parts calcium to one part magnesium is ideal for irrigation water. Likewise, high levels of Mg^{2+} (>50 ppm) can induce calcium and potassium deficiencies (Landis 1989).

Several ions can leave residues on foliage and accumulate on or eventually clog irrigation nozzles. Irrigation water with high levels of Ca^{2+}, Mg^{2+}, CO_3^{2-}, and HCO_3^{1-} (typically referred to as “hard” water) results in white deposits of calcium carbonate and magnesium carbonate on foliage. These deposits can also accumulate on the orifices of irrigation nozzles (Landis 1989).

Pests and Pesticides

Pests may be introduced into the irrigation water when surface water sources are used. Typically, weed seeds, moss, algae, and pathogenic fungi can be found in surface water sources (Baker and Matkin 1978). When surface water sources receive runoff from adjacent agricultural operations, *Pythium* and *Phytophthora* fungi can pose serious problems with damping-off during germination (Whitcomb 1984). Filtration and chlorination may be required to remove these pests from irrigation water.

Both surface and groundwater sources may become contaminated with pesticides. Pesticides may enter surface water supplies from runoff or over-spray from adjacent agricultural sites, and groundwater sources can be contaminated when a pesticide moves through the soil into recharge areas of the well or aquifer. Herbicide contamination poses the greatest risk for seedling nurseries. Seedlings may be stunted or die when irrigation water is contaminated with a herbicide. Specific assays are available to detect and characterize pesticide contamination in water.

pH

The pH of the irrigation water is an important factor that needs to be monitored and adjusted during seedling production. The pH is defined as a logarithmic expression of the hydrogen ion (H+)concentration with values ranging from 0 (very acidic), 7 (neutral), to 14 (very alkaline). The pH of the water and the growing substrate affect mineral nutrient availability. For container nursery operations where peat-based substrates are used, optimum nutrient availability occurs in a pH range of 5.2 to 5.5 (Peterson 1981). Specifically, conifers seedlings often grow best at a pH near 5.5 (Landis 1989).

Alkalinity is a measure of water’s ability to neutralize acids. It is generally reported in ppm or meq/L. One meq/L is roughly equal to 50 ppm $CaCO_3$. Carbonates and bicarbonates primarily influence alkalinity in irrigation water. Because alkalinity influences pH, and pH influences nutrient availability, it is important to have the alkalinity of your irrigation water checked. Since small containers are irrigated more frequently than larger containers, high irrigation water alkalinity will cause the pH of the substrate to increase over time.

The pH of the water can also influence disease management. Notably, pH levels greater than 6.5 can encourage the development of damping-off diseases during germination and early seedling development (Carlson 1983). Acidic substrates in the range of pH 4.5 to 6.0 will discourage damping-off. Alkaline irrigation water can also have a negative influence on certain pesticides. Their effectiveness is reduced by a process known as alkaline hydrolysis (Ruter 1999). Commercial buffering agents can be tank-mixed with many pesticides to counter the effects of water with a high pH.

Testing Water Quality

Water quality testing should be a regular routine in a quality control operation. Testing should be done during nursery setup, and periodic monitoring should occur during production. Testing and evaluation can be done by private laboratories or by university laboratories through the county cooperative extension office in many states. Basic tests should include a salinity test listing the major ions and their concentrations, EC, and pH. Additional tests can be performed to detect pathogens and specific pesticides if contamination is suspected.

Corrective Treatments

If problems are found with irrigation water quality several treatments may be available:

- Acidification
- Reverse osmosis
- Deionization, water softeners, chlorination
- Filtration.

Acidification is used to lower the pH of the water. Typically, an acid such as sulfuric, phosphoric, or hydrochloric acid is injected into the water to remove the ions CO_3^{2-} and HCO_3^{1-} (Landis 1989, Garber and Ruter 1993b). If corrective measures are not taken, the pH of the substrate will increase over time when alkaline irrigation water is used. For irrigation water that is too acidic, amendments such as dolomitic limestone can be mixed with the substrate before planting to control potential problems.

Reverse osmosis systems and deionization may be used to remove salt ions from saline irrigation water. These systems have high initial costs and require regular maintenance. Deionization systems have relatively slow treatment times and water must be stored for irrigation use (Landis 1989).

Water softener systems are not recommended for irrigation water treatment as they use Na^+ to covert “hard” water with high levels of Mg^{2+} and Ca^{2+} to “soft” water (Landis 1989). The Na^+ poses a greater risk for seedling damage than the Mg^{2+} and Ca^{2+}. Chlorination is used to remove pathogens such as fungi and algae from the irrigation water. Typically, liquid sodium hypochlorite (household bleach) or powdered calcium hypochlorite is added to the water. Direct injection of chlorine gas is cost effective but requires specialized equipment and poses greater risks to operators. Free available chlorine levels of 2 to 3 ppm are generally sufficient to kill fungi. Approximately 2.6 fluid ounces of household bleach (5.25 percent sodium hypochlorite) in 1,000 gallons of water will produce 1 ppm of free available chlorine (Baker and Matkin 1978). Simple test kits are available to measure concentrations of free available chlorine.

Filtration removes suspended particles such as sand, weed seeds, and algae. Filter systems are recommended to prevent suspended particles from damaging irrigation pumps, injectors, and nozzles. Screen, cartridge, and granular medium (sand bed) filter systems are available.

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DIAGNOSING TROUBLE SPOTS CAUSED BY AN IRRIGATION SYSTEM

John R. Scholtes[1]

ABSTRACT—I discuss a testing procedure to determine the water distribution pattern of a sprinkler irrigation system and steps that may be taken to improve uniformity of application. All irrigation systems require testing and maintenance to assure that water application is as uniform as possible. Even new systems installed to a manufacturer's specifications should be "field tested" before use on a crop (Landis 1989).

CONSIDER THE EFFECTS OF UNEVEN DISTRIBUTION UPON YOUR CROP

Uneven distribution is a factor that is universal in irrigation systems. A Coefficient of Uniformity (CU) of 85 percent is considered the minimum acceptable value for both agricultural crops (Zimmerman 1966) and for tree nursery crops (Shearer 1981). Uneven distribution leads to several consequences that should be considered. For instance, you must irrigate sufficiently to get the minimum required water onto the driest areas. Doing this will over water all other areas. This not only wastes water and causes the over watered areas to be too wet but it also over applies any materials being added though your irrigation system. It also leaches out soluble materials previously incorporated into your potting mix. In heavier mixes, the over watered portion of the crop may be suffering from too little oxygen available for the roots. If you are trying to apply materials such as fertilizers and pesticides through the irrigation system, you can use simple math to calculate the variation in application rates. These variations in available moisture, oxygen, nutrients pesticides, etc. may explain a lot about the performance of your crop. Some of these effects are clearly visible in the nursery; showing definite patterns tied to the locations of the irrigation nozzles. Other effects are not clearly visible. Especially when there may be other compounding factors such as poor mixing of the potting media or uneven compaction of the media into the containers. Testing by collecting representative samples at known points is the best way to check irrigation distribution.

BEFORE TESTING YOUR SYSTEM

Consider having your data analyzed by others. There are university programs and irrigation system vendors who utilize sophisticated analysis programs to calculate factors such as Uniformity Coefficient, Distribution Uniformity, Scheduling Coefficient, etc. They may also provide "3D" graphics or "density" diagrams allowing visual analysis of irrigation distribution. However, these programs are likely to have certain data collection protocol to be followed for the programs to work properly. Be aware that data you collect on your own may not fit into their program. If there is a chance that you will be working with a university specialist or a vendor, it is highly advisable that you contact these sources before you begin testing.

Some newer programs only require a single sprinkler and one or two lines of collection containers. The computer program will do the rest, filling in overlapping sprinklers, etc. These are "neat" programs and are intended to save you time and effort. However, these programs rely mostly upon theory. Uneven pressure at individual nozzles and even the collision of water droplets can cause actual distribution to vary from the theoretical. You may want to make your collections exactly as required by the program but also run a couple "check" tests of the system using a full grid layout. Even a few collection containers placed in a larger grid will allow comparing actual distribution with the theoretical.

TESTING YOUR SYSTEM (ADAPTED FROM MERRIAM (1978))

1. Equipment needed:
   - Pressure gauge(s)—In addition to the gauge mounted on your irrigation system to monitor water pressure at the controls, you will want a hand held gauge that you can use to monitor pressure along the lines of your irrigation sets. Depending upon the design of your sprinkler nozzles, you may need to add a small device called a "pitot tube" which can be inserted into the water stream in the nozzle to measure water pressure.
   - Hose and container—A hose that will fit over the nozzle and gather all discharged water into a container. Measuring this discharged volume within a certain time will allow calculation of nozzle output over time (i.e., gallons per minute). This is useful to check nozzle performance against manufacturer specifications to determine nozzle wear.
   - Water collection containers—Two to 50 or more will be needed depending upon size and density of grid. These must have identical top openings. Paper or plastic cups work well. For traveling booms, consider using a row of pill cups, test tubes, etc. that fit inside a row of empty containers placed perpendicular to the boom.

     Note: To calculate actual application rates (i.e., inches per hour) you will need to measure the tops of the collection containers and calculate the collection area. This is usually expressed in square millimeters or square inches.

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- Tape measure—Used to set out collection containers on the established grid. Also needed to measure the top opening of the collection containers.
- Paper—A preprinted form containing notes, section with grid marks to draw the grid, etc. Also to record trial results. (See attached example)
- Watch—A watch is needed to time application(s) of water during each test. A stopwatch is nice but a standard watch can be used.
- Graduated cylinder—Use to measure collected water. Should be accurate to 2 ml.
- Pencil—Record volumes of water collected.
- Calculator or computer (your choice)—Using raw collection data, one can calculate unending statistics. The mean volume collected and the percent of variation from this mean is a useful beginning point to determine just how uneven the distribution may be. A computer spreadsheet allows easy storage of records and graphing the results.

2. Lay out a grid of collection containers. Design a grid pattern between two or more sprinkler heads. The actual spacing of the grid needs to fit the seedling bed or container table. It can be varied depending upon the degree of detail needed. For instance, in a typical container bed situation, something like a 60 cm or even a 90 cm grid can be used to get a quick picture. A 15 to 25 cm grid may be chosen for fine-tuning the system. (Note: Once the grid spacing is determined, it is critical to place the collection containers at exact intervals with their tops level).
3. Record notes and sketch the grid onto a form. Develop a form onto which all data about the system and the test can be recorded for later reference. Include the "Test Identification Number". A number containing the year, month, day, and sequential test on that day (2001-01-15-01) is recommended. This type of system will provide for easy reference and, if used as a computer file name, will store your tests in the correct order in the file. Include a sketch of the grid being used. Sketch a north-facing arrow to show the orientation of the seedling bed and the collection containers. Draw in the location of the sprinklers (fig. 1).
4. Test the system. Water for a normal length of time. Record this time so the test can be repeated using other pressure settings, nozzles, etc. Measure and record the amount of water collected in each container. Use a graduated (laboratory style) cylinder or other suitable device to obtain an accurate measurement of volume in each collection container. If possible, record the collected quantities straight onto the paper grid. This will prevent confusion over where the collections were made and having the volumes listed on the grid will provide a quick visual analysis of the irrigation distribution pattern.

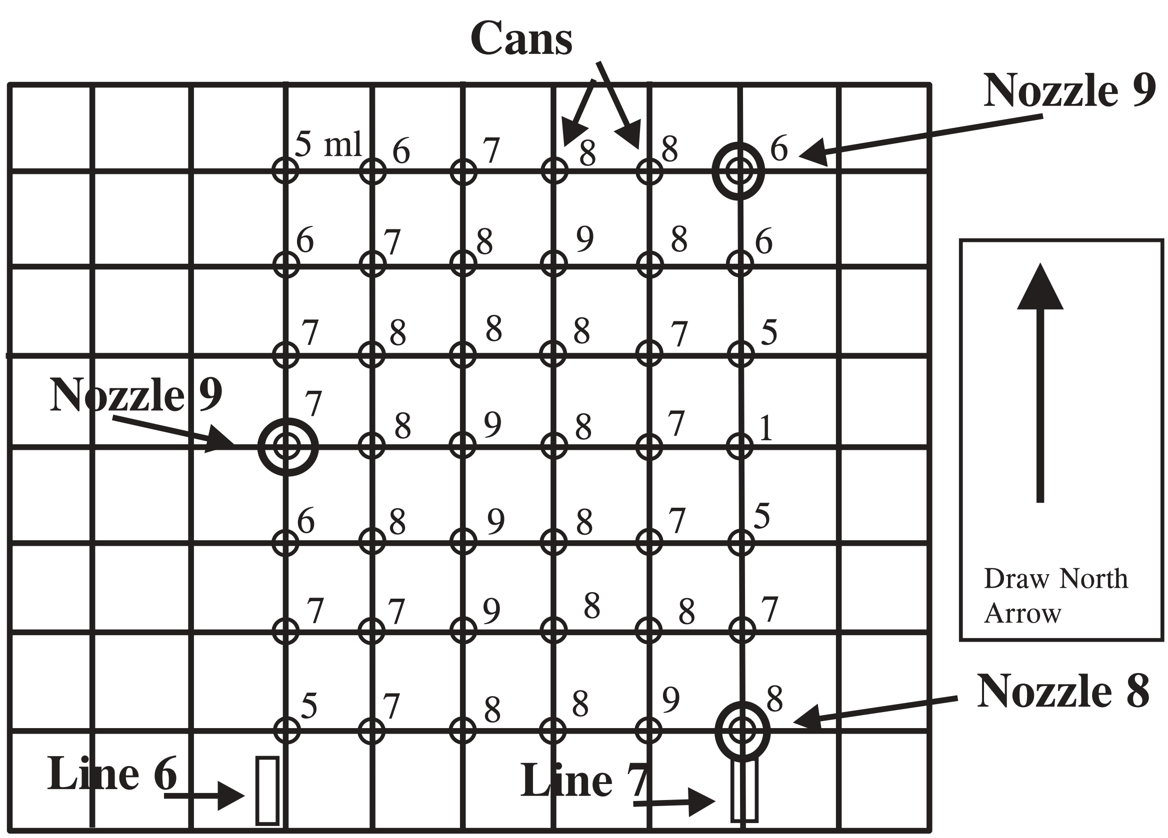

Figure 1—An example of a sampling grid.

For shelter house, shade house, or other open type facilities, you also need to consider wind conditions under which the system is operated. Be sure to record the wind direction and speed during each test. Add a compass and anemometer to your equipment list for such testing.

5. Follow up testing. Periodic checks of your irrigation system are required (at least once at the beginning of each crop). All nozzles wear over time. Especially nozzles lined with a soft material such as plastic or brass. Wettable powders such as fungicides are noted for increasing nozzle wear.

WATER DISTRIBUTION TEST RECORDS

There are any number of records that can be maintained. The following example of a test record combines system data, test data, and a sketch of the test layout with the collection data recorded directly onto the sketch. Doing so prevents field-to-office misunderstandings of where the data fits onto the grid. It also provides an on-the-spot visual of the test results.

IRRIGATION SYSTEM TEST RECORD EXAMPLE

Test number	2001-01-15-01
Nursery	Happy hollow
House or bed	House D1, table 6B
Irrigation system	Solid set
Nozzles	PDQ400
Spacing	9’ / 9’
Type	Triangular
Location of grid	Line 6 nozzle 9 and line 7, nozzles 8 and 9.
Collection container	6 oz plastic wine glass
Inside diameter of top	72mm
Duration of test	30 min
Wind	NA
System pressure	65#
Technician	I. R. space cadet
Date	01/13/2001
Time	15:00

EXAMINING THE DATA

Modern spreadsheet programs allow data to be examined and displayed relatively easily. As long as the data grid remains the same from one test to the next, once a base spreadsheet is developed, new tests can be examined by just entering the sample collection data into the spreadsheet. All calculations and graphs will automatically adjust to the new data. The following spreadsheet can be used or improved upon. (Following example utilizes Microsoft® Office 2000 Professional, Excel. Other spreadsheet/graphing programs would be similar. The instructions are specifically for a grid of seven rows with six containers per row. You will have to change the cell addresses given below for other grids.)

1. Folder and test number—Enter your spreadsheet program. Set up a folder “Irrigation Testing”, Name your spreadsheet “0000 Master Copy”. Use Save-As to save into your Irrigation Testing folder. Once this master copy is completed, use “Save As” to save this test and future tests using the test number as the file name. The test number should contain “Year, Month, Day, Sequential Test Number” such as “2001-01-15-01” for the first test taken on January 15, 2001. This sequence of numbers will keep all the tests in your folder in order for easy reference
2. Enter test number—Type “Test Number” in cell D1 of the spreadsheet. Format font to 14 Bold. Enter with right arrow. Move right one more cell to F1 and type in the test number from the first test. Format this also to 14 Bold. Add a Highlight or light shadow (from the tipping bucket) to this entry (cells F1 and G1) to indicate that this entry will need to be changed for each test. Down arrow to skip down a couple of lines and left arrow left to cell D4.
3. Enter collection data—Type in “Volumes From Collection Cups” enter using down arrow and then left arrow to cell C5. Type in volumes from the test record. Enter each volume using the right arrow until the first row is entered. Then down arrow to the next line and use left arrow back to cell C6 where you will enter the second row of data. Continue until all data is entered. Now select all cells containing the name and all data and enter a heavy line around it. Now select just the cells with data and either highlight or enter a light shadow over the selected block to indicate that these entries will need to be changed for each test. Now down arrow a couple lines below your raw data table and arrow to cell C13.
4. Calculate the sum of all collections—Type in “Sum of All Collection Volumes”. Enter with a right arrow and in cell G13 type in “=SUM(“ then select all cells in the data table above and type “)”. Arrow down and left to cell C14. This should enter the sum of all the collection volumes.
5. Calculate the average volume—Type in “Average Volume” and right arrow to cell G14. Type in “=SUM(“ then select cell G13, type in the division sign “/” and then type in the number of data points in the test. (count the data points in the table). Enter an “)” to finish the formula. Arrow down and left to D17.
6. Calculate the deviation from the average—Type in “Deviation (+ or -) From Average”. Enter with a down arrow and left to cell C18. Type in “=SUM(C5-G14)”. Hit “Enter”. Now copy this cell to the clipboard. Next, select this cell and a range of cells the same number down and across as the number of original volume data cells in the first box. Key “Enter” and you should have figures showing the difference between the original collection volumes and the average collection volume. Now select all cells containing the name and all data and enter a heavy line around it to form a box. Arrow down to Cell D27.
7. Calculate percent of deviation from the average—Type in “Percent (+ or -) From Average”. Enter and arrow to cell C28. Type in “=C18/G14*100” Hit “Enter”. Now copy this cell to the clipboard. Next, select this cell and a range of cells the same number down and across as the number of original volume data cells in the first box. Key “Enter” and you should have figures showing the percentages that the original collection volumes vary from the average collection volume . Now select all cells containing the name and all data and enter a heavy line around it to form a box.

The data boxes are of value in showing just where and how much the individual collection volumes vary, how much they vary from the average, and the actual percentage by which they vary. You can pick out the areas being over watered and under watered just by viewing these tables. The table of percentages tells you how much over and under the volumes are running and also allows you to spot calculate actual application rates of fertilizers, pesticides, etc. that are being added through the irrigation system.

Graphs

For a more visual look at the data, try using the graphing program for your spreadsheet. The original collection cup data can be shown in graphs by just highlighting the row or rows you want in the graph and then using the graphing wizard to develop the graph of your choice. These can be placed right onto the spreadsheet for easy viewing and printing. Using this technique, one can develop the graphs that may be useful for analysis of the tests. You should be able to print the entire spreadsheet with the calculations and the graphs on one page.

Surface Chart—One type of graph that is very visual is the surface graph. Select the entire range of Volumes From Collection Cups. Under chart type, select "Surface". Make other selections to format the exact graph that suits your needs. For use on a single spreadsheet, consider that less data on the graph is better as titles etc. take up a lot of space and do not add much to the visual impact of the overall graph.

Column Chart—A second type that may be useful is a "Column Graph" of the subtype "Clustered Column". To use this type, select data in one row. This clearly shows how volumes vary across the row. To visualize the complete grid, create a very simple graph for each row and line the graphs up on the spreadsheet.

Future Data

Using a spreadsheet format has the added value of only having to change the number of the test and the collection data (the cells that you highlighted or darkened) for each test. All the data and graphs are based upon this information and recalculate as you change the data. Be sure to save the spreadsheet for each test if you want a permanent copy. Use "Save As" and the test number.

FINE-TUNING YOUR SYSTEM

1. Check Location of Nozzles. They should be located at equal distances along the supply line.
2. Check the Alignment of Nozzles. For most nozzles to operate properly, they must be installed exactly on the top (or bottom) of the supply line. Any that are tilted may be causing distribution problems. Check them using the cup test. If they are causing uneven water distribution, they must be reinstalled.
3. Adjust the System. Water distribution of both solid set and traveling boom type irrigation systems can be adjusted by raising or lowering the height of the nozzles above the crop surface and/or adjusting the water pressure. Recheck water distribution using the cup tests.

   Notice: Don't forget that distribution will change dramatically as the crop grows higher and intercepts the water at different levels. Rather than waiting until you notice dry spots or actual growth differences in your crop, try some "pre-crop" checks with the cups raised to different levels. This will provide you with data to know when to raise the booms or sprinklers as the crop grows in height.
4. Other Corrective Measures. If the coverage is still not acceptable, try installing different nozzles. Last and most drastic would be to change the spacing of the nozzles or the type of system being used.

   Note: Changes being considered for a solid set system can be tested using a small "model" system of two supply lines with four nozzles. Test the water distribution of the trial system the same way you tested the production system

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BLANK IRRIGATION SYSTEM TEST RECORD

IRRIGATION SYSTEM TEST RECORD

Test number ______________________

Nursery ______________________

Name of nursery

House or bed ______________________

Name or code of shelter house, seedbed, polybag bed, etc. ______________________

Irrigation system ______________________

Type of system i.e. (Solid set or traveling boom) ______________________

Nozzles ______________________

Make and model ______________________

Spacing _____/_____

Distance between lines/nozzles

Type ______________________

Rectangular or triangular

Location of grid ______________________

Specific location of grid layout (Example: waterline #4, between sprinklers #8 and #9).

Collection container ______________________

Type of container (i.e. 4 oz. plastic Dixie cup)

Inside diameter of top ____________________ mm

Duration of test ____________________ min.

Length of time water collected

Wind ______________________

Speed and direction of wind during test

System pressure ______________________

Technician ______________________

Name of person(s) performing test

Date ___________________ Time ___________________

PREVENTION OF COLD DAMAGE TO CONTAINER-GROWN LONGLEAF PINE ROOTS

Richard W. Tinus, Mary Anne Sword, and James P. Barnett[1]

ABSTRACT—When longleaf pine (*Pinus palustris* Mill.) seedlings are container-grown in open fields, their roots may be exposed to damaging, cold temperatures. Major losses in some nurseries have occurred. Between November 1996 and February 1997, we measured the cold hardiness of container-grown longleaf pine roots by measuring electrolyte leakage (a) of greenhouse-grown and growth-chamber hardened seedlings representing minimum and maximum cold hardiness, respectively, and (b) of outdoor grown seedlings. Minimum tolerable root temperature was 25 °F, which varied little with season; a few degrees lower was lethal. Weather records at the W.W. Ashe Nursery near Brooklyn, MS, showed that damaging temperatures occurred on 7 nights per year on average. Covering the seedlings with black plastic overnight held rootball temperatures 10 to 12 °F above ambient air temperature and saved the crop twice in December 1996. However, the best management strategy is to outplant seedlings before the onset of damaging, cold temperatures because once outplanted, the seedlings are safe.

INTRODUCTION

In recent years, the technology for growing longleaf pine in containers has come into widespread use because of its success in field establishment and early height growth. However, container-longleaf pine is commonly grown in the open with the trays elevated for air pruning. This exposes the roots to ambient air temperature, which in winter can be cold enough to damage them, a situation that seedlings growing in the ground do not encounter.

In February 1996, a cold South-wide freeze received national attention because of the damage to fruits and vegetables. Also exposed to the freeze were some 400,000 container-grown longleaf pine seedlings at the USDA Forest Service W. W. Ashe Nursery in southern Mississippi. Following the freeze, the seedlings looked fine, so they were shipped to the ranger districts and planted, but within several weeks they were all dying. We determined that the seedling roots had been killed, even though the tops were undamaged, so we initiated a study to find out:

(1) How low a temperature can the roots tolerate without damage, and how does this vary seasonally?

(2) When are damaging temperatures likely to occur and how often?

(3) What can we do to protect the seedlings?

COLD HARDINESS

We grew longleaf pine seedlings at Flagstaff, AZ, during the summer. After reaching a suitable size the seedlings experienced a fall and winter simulation in a growth chamber while the rest of the seedlings remained in a warm greenhouse. We then measured cold hardiness of the two groups, which determined maximum and minimum cold hardiness.

Concurrently, at Pineville, LA, we measured cold hardiness of longleaf pine seedlings from the Ashe Nursery at 2-week intervals from November 1996 through February 1997.

We used the electrolyte leakage test at both the Arizona and Louisiana locations (Rietveld and Tinus 1987, Burr and others 1990). We cut the root-segment tissue into reasonably uniform samples and placed them in test tubes with a small amount of deionized water. We froze groups of tubes at a series of successively lower temperatures; then thawed and placed them on a shaker for 24 hours. We measured the conductivity of the solution, and damage to the tissue from the amount of electrolytes that leaked out. Then we boiled the tubes to kill the tissue completely, shook them for 24 hours, and remeasured.

Using the two conductivity measurements for each tube, we calculated an index of injury. From a regression equation calculated from the whole data set, we calculated the temperature corresponding to the 10 percent, 30 percent, and 50 percent indices of injury.

First, comparing the succulent greenhouse grown seedlings with the fully hardy seedlings from the growth chamber showed only a few degrees of difference in cold hardiness, so the seasonal variation is close to zero (table 1). Second, the difference is only a few degrees between temperatures that damage seedlings beyond being usable and those that do not, so the margin for error is quite small.

We corroborated these findings in the Louisiana lab that winter. Differences in cold hardiness during the late fall and winter were small. Maximum cold hardiness occurred in December and was lost in January and February (fig. 1). Therefore, the answer to the first question is simple: Do not let the roots get colder than about 26 °F at any time.

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Table 1—Cold hardiness of longleaf pine roots from a warm greenhouse and after hardening in a growth chamber

Index of injury (percent)	Corresponding temperatures (°F) Nonhardened	Hardened	Expected damage
10	26aA	25aA	Not significant, will recover
30	25aA	22aA	Heavy damage, not shippable
50	24aA	18bB	Dead

Values with the same letter are not significantly different at p=0.05. Lowercase is for columns, uppercase for rows

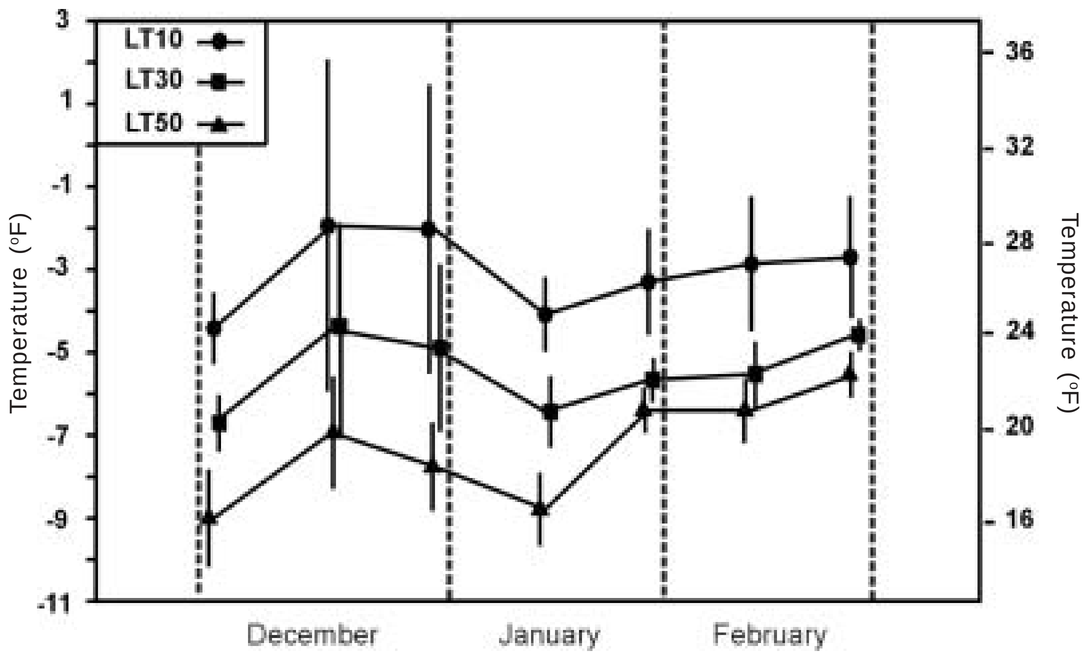

Figure 1—Root cold hardiness of longleaf pine seedlings grown at the USDA Forest Service W.W. Ashe Nursery in Brooklyn, Mississippi during 1996. Temperatures associated with an index of injury equal to 10 percent (LT10) are the minimum temperature without significant damage to seedlings. Temperatures associated with indices of injury equal to 30 percent (LT30) and 50 percent (LT50) are temperatures at which seedlings will be damaged beyond use.

RISK PERIOD

To assess the risk of damaging temperatures by month, we used 10 years of data from a weather station that had been operating at the Ashe Nursery since 1985. At Ashe Nursery in southern Mississippi, the most risky period is December 15 to February 15. During an average year, there will be seven nights between December 1 and February 28 when exposed container longleaf may need protection, and one night every other year that may be so cold that they cannot be protected. Figure 2 illustrates the situation. In the winter of 1996–97, there were two occasions when the minimum temperature was below 26 °F, which could have damaged the seedlings.

PROTECTION

How can the seedlings be protected? In March 1996 when we tested covering the exposed seedlings with black polyethylene, overnight heat retention kept the rootballs 10 to l2 °F warmer than the ambient outside air temperature. Covering appears to be a viable way to protect the seedlings from short-term cold spells.

In early December 1996 a hard freeze was forecast that would be cold enough to damage the longleaf seedlings, so the Ashe Nursery crew purchased all the black plastic they could find in three nearby towns in southern Mississippi and covered the crop. After the freeze, electrolyte leakage tests showed that there was no damage to the covered seedlings,

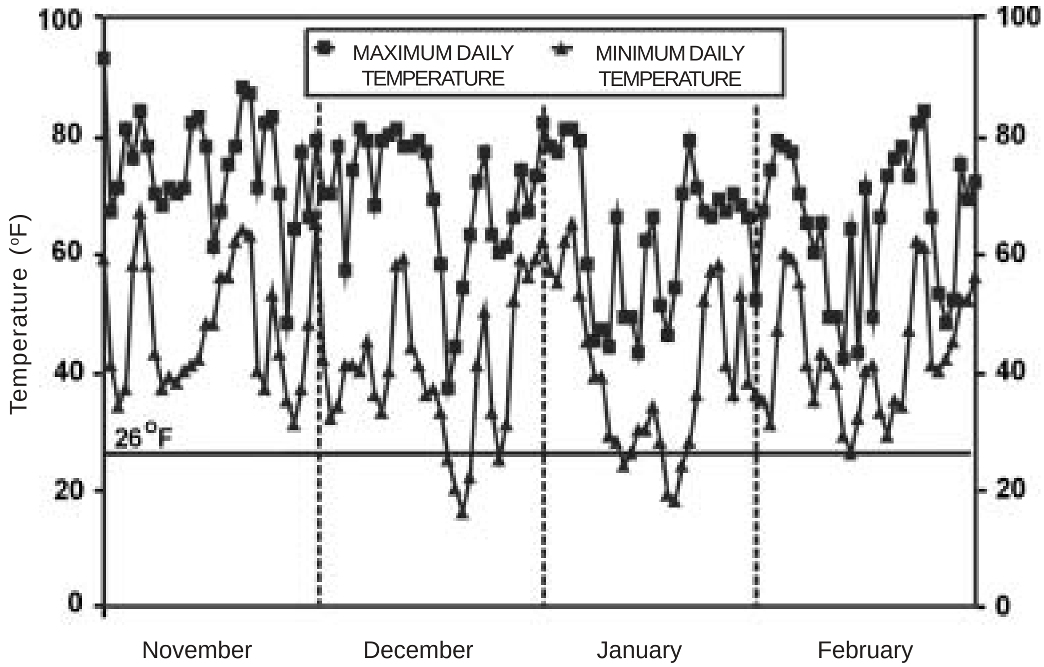

Figure 2—Daily maximum and minimum temperatures at the USDA Forest Service W.W. Ashe Nursery in Brooklyn, Mississippi in November 1996 through February 1997. On two occasions the exposed longleaf pine seedlings needed protection to prevent root damage by cold temperatures.

but a sample of seedlings that were not covered were damaged. Apparently, the plastic cover worked. Plastic covers have saved the crop several times since, most recently January 3 through 5, 1999, when overnight air temperature dropped to about 13 °F. The rootballs of seedlings covered with plastic did not freeze.

Incidentally, clear plastic works almost as well at retaining heat overnight as black. However, if the following day is sunny, it is important to remove the plastic quickly before it overheats the seedlings. Covering with plastic may be a simple solution, but it is not cheap, or easy, especially if the wind is blowing. The best solution is for customers to take their seedlings and outplant them before any damaging cold weather hits. Once in the ground, with its large thermal reservoir, the roots of longleaf pine seedlings are safe. This method was demonstrated in December 1996 by retrieving longleaf seedlings that had been outplanted before the freeze. The electrolyte leakage test showed no damage to the roots.

CONCLUSIONS

Unlike bare-root seedlings, outdoor-grown container stock is ready to go to the field any time during the fall, so there is no reason not to begin planting the seedlings as soon as there is sufficient moisture in the soil. This strategy may involve educating tree planters who are not aware of the difference, but it would entirely avoid the need for heroic efforts to protect the seedlings at the nursery.

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MARKETING AND SEEDLING DISTRIBUTION OF LONGLEAF PINE SEEDLINGS

Mark J. Hainds[1]

The Longleaf Alliance, a partnership of people and organizations interested in longleaf pine, started tracking longleaf pine (*Pinus palustris* Mill.) seedling production in 1996. Total Longleaf seedling production has increased annually from 1996 to 2000. Bareroot seedling production decreased from 1996 to 1997, and decreased again from 1997 to 1998. Many nursery managers decreased longleaf production because demand for loblolly and slash were high in this time period, and more seedlings can be grown per square foot of nursery bed with loblolly or slash than with longleaf pine. Overwhelming demand for longleaf due to CRP Program and surplus production of loblolly and slash led to increased bareroot longleaf production from 1998 to 1999 and 1999 to 2000.

Containerized longleaf seedling production has increased annually since 1996. The number of nurseries growing container longleaf seedlings increased from approximately 24 in 1996 to around 42 nurseries in 2000. Overall, containerized seedling production increased by approximately 240 percent in this time. Despite this large increase in container longleaf supply, virtually all container seedlings produced were sold and planted.

Frequently, advertising and marketing require a significant percentage of a new business's annual budget. This has not been the case with nurseries growing longleaf pine. In the face of an overwhelming demand, many new nurseries can sell their seedlings through contacts with existing nurseries, or through the Longleaf Alliance. During periods of short supply, the Longleaf Alliance maintains a list of landowners and foresters in search of longleaf pine seedlings. In several cases, the Longleaf Alliance has provided sufficient referrals to sell 100 percent of a new nursery's production.

Additionally, the Longleaf Alliance maintains the "Longleaf Nursery List." "The Longleaf Nursery List" is a comprehensive listing of nurseries that grow longleaf seedlings for sale to the public. Foresters, tree planters, the forest industry, State forestry commissions, and many other agencies use the "Longleaf Nursery List" as a tool to locate seedlings for their regeneration needs. To be included in the "Longleaf Nursery List", all one must do is fill out and return a longleaf nursery questionnaire to the Longleaf Alliance. This list is updated several times over the course of a year.

Production of container-grown longleaf seedlings is centered in South Georgia, while production is also increasing rapidly across Alabama. Georgia has the largest amount of farm ground being converted to longleaf through the Conservation Reserve Program (CRP). Consequently, demand is sufficient to deplete supply at this time. In the absence of the CRP, Georgia would likely have an excess supply of longleaf pine seedlings.

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EXPERIENCE OF THE SMALL GROWER

Emmett Jordon[1]

ABSTRACT—The small grower cannot afford costly facilities, equipment, or containers. The grower usually does about everything by hand and gets help from family members and friends to get started. I describe the approach I use to produce longleaf pine container stock.

INTRODUCTION

There are many decisions that have to be made when a small grower decides to venture into the production of longleaf pine container stock. A major one is how to market the seedlings. Once this issue is resolved, decisions must be made about facilities, containers, seeds, and growing methodology.

SEED

I try to get longleaf pine seeds with at least 80 percent viability so that I single sow in the trays. I soak in benomyl for twelve hours and then stratify by putting into a refrigerator for a week before planting.

DEVELOPING FACILITIES AND GROWING TECHNIQUES

One of the first decisions that must be made is the type of containers that will be used. Generally, two types are available—Styrofoam and plastic. I decided to use Styrofoam trays because they are less expensive to buy and they can be used with inexpensive tables. One advantage of the plastic trays is that the root plugs are easier to extract.

I buy a premixed growing medium because I cannot afford a soil mixer and specify that the pH should be between 5.0 and 5.5. Osmocote slow-release fertilizer is added to the medium to limit the amount of fertilization that must be added with the watering system during the growing period.

The trays are filled by hand, but wet the medium before use. A small operation cannot afford a tray filler. The seeds are planted by hand, also. I replant cavities without a germinating seed within 14 to 20 days.

A stake-type irrigation system is sufficient. You must be sure that the irrigation pattern is uniform and overlaps. I use an existing well to provide irrigation water and use phosphoric acid to lower the pH to about 5.0. I do this to prevent the pH of the medium rising and making the seedlings more susceptible to disease.

A two-gallon sprayer is the economical choice far applying fungicides. I spray fungicides every week for the first two months. After that, I spray every two weeks or as needed.

Additional fertilizers are applied using a siphon that connects to a water hose. This is an efficient technique.

Stay in close contact with the local county agent or state container specialist to get help and advice with problems that are encountered.

Harvest the seedlings and box yourself because hiring outside labor is expensive.

CONCLUSIONS

I hope that I have been helpful in providing information on the practices of the small grower. A small grower needs to have all the trees sold before he plants. Such a grower can cater to local people's needs with more efficiency by providing fresh trees and insuring that they are of high quality.

Through these methods, the small grower can compete with the medium to large growers. Growing pine seedlings is not a fast way to make money. It takes two to three years to show a profit with good crops.

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GROWING LARGE QUANTITIES OF CONTAINERIZED SEEDLINGS

Tim Pittman[1]

ABSTRACT—The sowing of large quantities of longleaf pine (*Pinus palustris* Mill.) seed into trays depends on the quality of the seed and the timing of seed sowing. This can be accomplished with mechanization. Seed quality is accomplished by using a gravity table. Tray filling can be accomplished by using a ribbon-type soil mixer and an automated tray-filling machine. Without automation, it would be economically unfeasible to sow and grow large quantities of quality seedlings.

INTRODUCTION

Nursery managers have a window for sowing longleaf pine (*Pinus palustris* Mill.) seeds of about 40 days, no matter if you are growing 100,000 or 4,000,000 seedlings. Growing container stock is one of the most labor-intensive cultural practices there is in the industry compared to bareroot seedling production. Seeds sown too early can have the germination delayed due to low soil temperatures, which in turn allow pathogenic activity during this dormant stage. Seeds sown too late can suffer with poor germination due to fluctuations of heat and pathogenic activity as well as activity from birds, squirrels, rats, fire ants, and raccoons.

SOWING LARGE QUANTITIES OF TRAYS

There are three ways to accomplishing the sowing of longleaf seeds within the limited sowing window. These can be used alone or in conjunction with one another.

Automation—Soil and amendments can be custom blended in soil mixers and tray filler machines, and seeding can be done by automation.

Hand labor—Custom blended premixed soils can be purchased so that filling and seeding of each individual tray can be done by hand.

Extended hours—Sixteen to 24-hour days, double shifts, or split shifts can be used in order to fill and seed the trays within the time window.

Our nursery uses a combination of all these sowing methods in order to accomplish this task.

SEED QUALITY

Using the best seeds available when they are available can make the job a lot easier. Using high-germination rated seeds; i.e., 90 to 95 percent, is better than using seeds germinating in the range of 50 to 75 percent. We have been using a gravity table in order to separate the heavier seeds from the lighter seeds, hence increasing our chances of a better germination rate.

SOWING PROCEDURES

Seed Handling

Seeds are taken from our seed freezers where they have been stored at an average temperature of about 8 °F. They are then placed in burlap bags and put in a water soak for 24 hours. After this, they are transferred to plastic bags and placed in the cooler at an average temperature of about 50 °F for a period of about 7 days. After 7 days of storage time, they are then dried to touch in order to facilitate machine planting. (Wet seeds do not flow in the planters too well.)

Soil Mixing

Custom blended soil (Verlite Corporation Forestry Mix) is placed in a Boulden and Lawson soil blender where it is fluffed. Fertilizer and soil acidifiers are mixed in at the following rates:

- Soil—Six bags (24 cubic feet of Verlite Forestry Mix® (50 percent Canadian peat, 30 percent Polystyro® beads, and 20 percent coarse grade vermiculite).
- Fertilizer—4 pounds Miester 17-6-10, 9-month formulation with minors (Helena Chemical Co.)
- Soil acidifier—2 pounds (Southern Agriculture Chemicals)

These are mixed together and water is added; then this mix is transferred to the tray-filling machine.

Tray Filling

Can Am # 3 trays are brought in from the storage area where they are placed in the tray filling machine (Boulden and Lawson flat filler model #13304)® where they are filled, the soil is compacted and rolled to a depth of about 1/2 inch, and the trays are palletized.

Sowing

The soil filled trays are sown by hand and placed in two automated seeding machines from The Old Mill Company.

Topping

The sown trays are then transferred to a topping table where a mixture of two-thirds coarse grade vermiculite and one-

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third perlite is poured over the trays and the excess screened off. This mixture is prewet in order to cut down on the amount of dust that both products give off. The perlite is used as an extender in order to offset the high cost of the vermiculite. The trays are then stacked onto trailers to be transported to the fields, where the seeds germinate and grow in full sun light.

CULTURAL PRACTICES

Herbicide Applications

From about two to four days after sowing, the first application of Goal® herbicide is applied before germination. This pre-emergent application is applied at a rate of two-quarts per acre. At approximately 10 to 15 weeks after germination, a lighter dosage of Goal herbicide is applied at approximately 6.4 ounces per acre. This is applied at biweekly intervals for the duration of the active weed growth period.

Fungicide

Fungicides are primarily applied on an as needed basis. However, Captan® fungicide is applied approximately 6 weeks after sowing to help combat some of the dampening off and root-rot fungi. This is applied one time using the bench treatment according to labeled directions.

Thinning and Transplanting

After the Cam Am trays have been sown, bulk seeds are put in 2- by 4-foot plywood trays with the soil mix, in order to have transplant stock that is about the same age as the germinated stock. Approximately 9 weeks after germination, all the trays are picked up out of the field and brought back inside the building in order to be thinned and transplanted.

The planting tool of choice is a butter knife with a sharpened V grove ground into the point. This inexpensive planting tool aids the planter in the elimination of J-rooting of the containerized stock. Thinning and transplanting should be completed by August 1.

Normally you can expect about a 15 percent loss of stock, so every effort to maximize stocking will help you in lowering your losses. Some people may elect to go ahead and accept up to 20 percent loss, but when you are dealing with large quantities, even a 10 percent loss out of 4,000,000 is 400,000 seedlings. Therefore, every effort is taken to ensure as close to 100 percent stocking as possible.

Supplemental Feeding and pH Control

During the growing season you may find that your pH will start to rise, particularly if the irrigation water is high in lime. Weekly applications of sulfur WP are applied at a rate of approximately 22 pounds per acre. We are currently looking into the possibility of acid injection in order to help reduce water pH. Along with the pH problem, you will run into a nutritional problem. To help combat this problem we use liquid fertilizers and chelated iron at these times and rates:

- Week 10 after sowing: Peters 9-45-15 is used at a rate of 11 pounds per acre. This formulation is used to help promote rapid root development, particularly in the newly transplanted stock.
- In August a balanced 20-20-20 fertilizer with minors is used on a weekly basis to promote a richer greening effect.

SHIPPING

Shipping usually starts around November 1. Many people would like to plant before freezing weather, allowing the seedling to harden off before colder temperatures set in. Trays are taken out of the field and the seedlings are extracted from the tray and placed in a 1-1/9-bushel waxed produce box. After 125 seedlings are placed in the box, the boxes are loaded onto refrigerated trucks for shipment throughout the State of Florida. On a standard refrigerated 40-foot trailer, approximately 120,000 to 130,000 seedlings can be shipped. This is more economical than leaving the seedlings in the trays and shipping the tray to the planting sites.

FIELD PLANTING CONTAINERIZED LONGLEAF PINE SEEDLINGS

Dale R. Larson[1]

ABSTRACT—The difficulty in establishing stands of longleaf pine (*Pinus palustris* Mill.) by artificial regeneration techniques has been a major factor in the decline of the number of acres occupied by this species in the Southeast. Many landowners and managers have been reluctant to plant longleaf because of its history of poor survival. Loblolly pine (*Pinus taeda* L.) and slash pine (*Pinus elliottii* Engelm.) now occupy many sites that longleaf pine dominated in the past. A renewed interest in longleaf regeneration has been developed in the past several years, and a substantial number of acres are now being reforested with longleaf pine. Research, development of containerized longleaf pine seedlings, and improved management practices have done a lot to eliminate most of the difficulties encountered in artificially regenerating longleaf pine stands.

INTRODUCTION

Longleaf pine (*Pinus palustris* Mill.) ecosystems dominated a reported 90 million acres of the Southeast at the time of early settlement. Less than 3 million acres of longleaf still exist in the Southeast, most of it in the Coastal Plains of the Carolinas, Georgia, Florida, Alabama, Mississippi, Louisiana, and Texas (Gjerstad and Johnson 1997). The reason for the decline was mainly because of difficulties in regeneration of the species. Longleaf pine can stay in the "grass stage" for the first seven or more years of its establishment. In this stage, it has no stem and is extremely vulnerable to competition. If it does survive, a significant percentage of growth will have been lost, and the stand rotation is extended. Few, if any, forest landowners or managers want to have a tract of land sit idle for 7 years or more! The developments of containerized longleaf seedlings, and improved silvicultural practices, have done much to overcome the challenge of longleaf regeneration. By choosing the right site, utilizing high quality containerized seedlings, demanding quality-orientated planting practices, and taking advantage of improved silvicultural techniques, longleaf pine can be successfully established within its natural range.

SITE

Habitat

Longleaf is found in well-drained sandy soils of flatlands and sand hills, often in pure stands (Little 1980). Longleaf will perform well on poorer sandy soils where loblolly and slash do not grow satisfactorily. Longleaf is highly drought resistant because of its deep taproot. Longleaf is also very fire resistant, and this can be used as an advantage in competition control, stand management, and regeneration. Fire is used to control brown spot disease (*Scirrhia acicola*) in young, natural, or planted longleaf stands (USDA 1989).

Range

The range of longleaf is the Coastal Plain from southeast Virginia south to east Florida, and then west to east Texas. It is usually found below 600 feet in the Coastal Plain and up to 2,000 feet in the foothills of the Piedmont (Little 1980).

SITE PREPARATION

Site preparation can range from a clean clear-cut to a mechanically prepared site. The economics and silviculture requirements rule this decision. Some of the factors to keep in mind are the presence or potential of competition, terrain, and the probability of erosion on the site. From experience, we have found that initial survival is not dependent on site preparation in most cases. The qualities attained on the planting job and competition control are the main factors encouraging early emergence from the grass stage and stand establishment. Early season weed control and/or a release treatment are essential. The longleaf seedlings must be free of competition during the first growing season in order for them to come out of the grass stage and initiate early height growth.

CONTAINER-GROWN SEEDLINGS

Container-grown longleaf seedlings come in a variety of sizes. The main points to consider are vigor, needle length, plug quality, and root condition. The seedlings should have a good green color with needles 6 inches or more in length. The plug should be firm, moist, and durable to hold up under planting conditions. The taproot at the bottom of the plug should be air pruned and callused. Lateral root tips visible on the outside of the plug should be firm and healthy. Visible mycorrhiza is desirable. Root collar diameter should be 3/16 to 1/4 inch. Although it is hard to see, a dormant bud should be present. The seedlings may be shipped in the containers that they were grown in, or the plugs may be pulled and packed in boxes for transport. In the field, an all-wheel-drive four-wheeler is a very useful piece of equipment to transport bulk seedlings to the planting crew personnel.

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PLANTING

Timing

In general, fully developed container seedlings of all species can be planted at anytime during the year. They are very useful in reforestation of problem sites. Some examples would be sites that are flooded during or immediately following the normal planting season, sites that possibly have seasonal drought problems, and interplanting during the growing season on sites that have unacceptable stocking. Container longleaf seedlings are very suitable for fall planting. As long as there is sufficient ground moisture, container longleaf seedlings can be planted from mid-September to late November with very good results. It is my opinion that fall is the best time to plant container longleaf seedlings in the Southeast. The seedlings planted during this period have some time to initiate root growth before winter dormant conditions. Initial root growth of an inch or more is not uncommon on fall-planted seedlings. In the spring, these trees will have a head start over trees planted during the winter months (December to March).

Stocking

Longleaf pine is adapted to growing at a heavier density than loblolly or slash. A good site can easily support 600 or more stems per acre. A suitable range to work with would be a stocking of 544 trees per acre (8 by 10 feet) to 622 trees per acre (7 by 10 feet). The site and the long-range management plan for the stand will have a direct influence on the initial stocking and spacing choices. The width between rows and the distance between trees in the row can be determined by the landowner's preferences.

Methods

Longleaf pine can be successfully planted using most of the conventional tools. Hand crews using container dibbles, standard dibble bars, hoedads, and planting shovels have been used to establish longleaf plantations. Container seedlings can also be machine-planted with high survival rates. As long as the tool will make a satisfactory opening to plant the seedling, good survival can be expected. The key to good survival with container longleaf, planted by hand or machine, is the depth that the plug is planted. The top of the plug must be covered to prevent moisture from wicking out of the growing media, but the seedling's bud should not be covered. Care must be taken to assure that the plug will not be uncovered by erosion or the bud covered by soil washing in on top of the seedling. Mechanically prepared sites must be fully settled before planting. Packing the soil around the plug is also important. Air pockets will damage or kill a container seedling just as quickly as a bareroot one. Good crew supervision is important on container planting jobs. A working supervisor or leader should be present with the crew at all times. The landowner or his representative should, at the minimum, audit planting jobs on a daily schedule.

SUMMARY

Longleaf pine can be successfully regenerated by artificial methods. Using container seedlings and sound silvicultural practices will help to make the task possible. Common sense and attention to detail will help you achieve the goals that you set. Tree nurseries and seed orchards provide a wide variety of pine and hardwood seedlings for landowners. Although the quality of the seedlings has been greatly improved through research in recent years, survivability depends largely on care taken in storing, transporting, and planting. (Georgia Forestry Commission 1989) The landowner has the responsibility to ensure that everything is done in the proper manner and on schedule. A good goal to keep in mind is that the trees that you are planting today will be the stand you will have to manage tomorrow. A high-quality planting job will go a long way to ensure that there will be a good, fully stocked stand to manage. This will ultimately provide the maximum volume of high value products for your investment of time and capital.

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This publication, a compilation of 20 papers concerning nursery production of longleaf pine seedlings in containers for reforestation, is a summary of longleaf pine workshops held in 1999 and 2001. The Longleaf Alliance and the USDA Southern Research Station and Southern Region Cooperative Forestry organized the first workshop in 1999. It was held in Jesup, Georgia, on September 21–23, 1999, and 15 papers were contributed. The University of Georgia Cooperative Extension Service hosted the second meeting on January 16–18, 2001, in Tifton, Georgia, and 5 papers are included from that effort. Papers are presented in an order that reflects a typical growing season and include information on nursery start-up costs; seed collection, processing, and treatment; irrigation and fertilization practices; container specifications; target seedling characteristics; water quality and irrigation concerns; experiences of small and large operators; pest control; marketing; and field planting.

Keywords: Forest tree nurseries, *Pinus palustris*, reforestation, seed and seedling physiology, southern pines.