ARTIFICIAL REGENERATION OF SHORTLEAF PINE

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ABSTRACT

The artificial means for establishing stands of shortleaf pine seedlings are reviewed. In addition to the relative merits of direct seeding and planting of bare-root and container seedlings, techniques that should help ensure successful stand establishment are discussed.

INTRODUCTION

Artificial regeneration of shortleaf pine holds great promise for increasing the productivity of major forest sites in the interior South. Most current shortleaf stands are of natural origin, although millions of acres have been planted and large acreages seeded. Natural regeneration will continue as an important shortleaf management technique in the future. However, the need for artificial regeneration is great and will continue to increase due to (1) deterioration of natural stands and increasing encroachment of low quality hardwoods, (2) the opportunity to increase stand growth by the use of genetically improved seedlings, and (3) the improvement in productivity by strict control of spacial distribution of seedlings.

ARTIFICIAL REGENERATION OPTIONS

Artificial regeneration options available to the forest manager normally include planting of bare-root and container stock, and direct seeding. What are the bases of selecting one technique over another? Planting provides a higher assurance of success than direct seeding, but seeding may be the best or only option for some situations. Direct seeding provides a rapid method of regenerating large acreages of open cutover land. However, such large areas are not common in the interior South where the typical reforestation site is 250 acres or less. Seeding is still an ideal technique to quickly regenerate large areas following wildfires or where terrain is difficult to plant. Seeding also provides cost conscious

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small nonindustrial forest landowners with a relatively inexpensive option for regenerating their lands. Comparisons of shortleaf pine growth after seeding and planting indicate that no significant differences occurred after 11 years (Phares and Liming 1960).

Compared to seeding, planting offers better control of stocking, makes more efficient use of expensive, genetically improved seeds; makes thinning and harvesting operations easier to accomplish, and prevents the need for precommercial thinning. Planting of container seedlings is an artificial regeneration option that has become available only in the past few years. The use of container-grown shortleaf pine seedlings has not gained widespread popularity because bare-root stock is usually relatively easy to procure, generally reliable, and because high quality container seedlings have been difficult to obtain. However, bare-root seedlings may not provide the desired results in some situations, and the use of container seedlings should be considered. Container seedlings can be used to: (1) improve survival and growth, particularly on sites difficult to regenerate; (2) extend the planting season by allowing regeneration of dry sites in the fall and wetlands that are subject to winter flooding in the spring, and (3) obtain greater flexibility in seedling production to meet unexpected demands.

If container seedlings are grown in sufficient quantities to take advantage of the economics of scale, they will be cost competitive with bare-root stock (Guldin 1983).

SITE SELECTION AND PREPARATION

No "typical site" exists for shortleaf pine. This species does grow best on moist, well-drained sites. However, shortleaf is adapted to and usually planted on the drier, poorer quality, and more mountainous sites of the interior South that are north of the range of loblolly pine. It is the preferred species on south- and west-facing slopes where soil moisture usually is critical. Soils in much of this mountainous region developed from metamorphosed sandstone, shales, and stony colluvium; and abundant rock is common in most soil profiles (Wittwer et al. 1986). Sites are droughty and difficult to plant. On better quality sites, hardwoods enter succession early and became more competitive as stand age increases. Upon harvest, then, hardwoods are a significant component of the stand unless site preparation is used to encourage successful establishment of pine on the reforested site.

Both survival and growth of shortleaf pine are often improved by site preparation. Such action addresses residual hardwood sprouting and grasses and herbaceous weeds that present serious competition problems. Several site preparation techniques are commonly used or have potential for use preceding the planting or seeding of shortleaf pine: (1) prescribed burning, (2) mechanical techniques, (3) chemical treatments, and (4) combination treatments.

Prescribed burning

Burning is a tool valued for its economy in preparing sites for reforestation if a prescribed burning program is established several years prior to harvesting. The routine use of burning beginning early in stand development results in smaller and fewer competing hardwoods when reforestation occurs. A prescribed burn in late November or early December, after leaf fall, is an effective and inexpensive way to reduce a heavy litter layer in preparation for direct seeding. The fire should consume only the loose, dead leaves, leaving a thin layer of duff. The hardwood overstory could then be removed by injection with chemicals. Usually, burning must be used with some other site preparation technique such as mechanical or chemical treatments.

The advantages of prescribed burning for site preparation are: (1) economy, when compared to mechanical or chemical means; (2) its use with caution on steep terrain; (3) its not being a cause of soil compaction, and (4) it's resulting in easily planted sites. Disadvantages include: (1) fire control that can be difficult and expensive; (2) air pollution that may be a problem; (3) intense burns that result in erodible conditions on some sites; and (4) resprouting if fires do not kill roots and root crowns.

Mechanical techniques

Mechanical site preparation includes a wide range of techniques and is probably the most reliable means of obtaining a stand of adequately stocked, free-to-grow shortleaf pine seedlings. There are basically four kinds of mechanical techniques: (1) crush or knock down the residual stems, but leave the debris in place (roller drum chopping), (2) knock down residual stems and pile the debris (shear and windrow), (3) whole tree harvest of standing trees (which combines site preparation with final harvesting), and (4) loosening of the soil to allow free drainage and aeration and provide channels to collect surface run-off (ripping). Of the first two techniques, foresters usually prefer roller drum chopping because of less soil disturbance, compaction, and nutrient depletion (Haywood 1982). Shear and windrowing is used when there are too many large residual stems for tree crushing to be effective or if the residual debris will hamper other operations. Yet on many upland sites, such intensive culture is unwarranted because the other mechanical treatments will produce similar results (Haywood et al. 1981). Poorly applied mechanical site preparation can also displace topsoil and organic matter and increase the potential for soil erosion. Thus, soil stability, slope, and timing of establishment of plant cover should be considered when selecting a technique.

Ripping of eroded, compacted, or rocky sites has improved performance of shortleaf and loblolly pine seedlings (Berry 1979). Recent research conducted in the Ouachita Mountains of Arkansas and Oklahoma has shown that height growth of loblolly pine after two growing seasons was increased 10 percent by ripping alone (Wittwer et al. 1986).

Chemical treatments

Herbicide treatments are a viable alternative to mechanical site preparation and are highly versatile tools for the landowner. They expose no mineral soil but are effective in retarding competing vegetation. Chemical site preparation can be accomplished by single stem treatments or broadcast applications. Since there are a number of chemicals available, selecting the most appropriate may be a problem because many factors influence herbicidal behavior. These include weather conditions before, during and after treatment; soil moisture levels; texture and structure of the soil; kind and vigor of the treated vegetation; the herbicide used and its formulation, and the quality of the application job. Not all of these factors are controllable. However, the landowner should have reasonable success by following the instructions on the herbicide's label. Guidelines are usually available from the Cooperative Extension Service in each state.

Under many conditions, herbicides are used most effectively in conjunction with either mechanical treatment or prescribed burning.

Combination treatments

A combination of mechanical, burning, or chemical treatments is usually most effective for site preparation. A combination of mechanical techniques and prescribed burning is commonly used. For example, mechanical roller-drum chopping followed by burning after the downed vegetation has browned is an effective technique for many shortleaf pine sites.

Herbicides and prescribed burning have also proved to be an excellent site preparation technique under appropriate conditions. The method has two variations, one termed "brown and burn" and the other "spray and burn" (Stewart 1978). The brown and burn method uses contact herbicides to desiccate leaves and twigs before burning. Because contact herbicides are not translocated into roots, they will not prevent resprouting after burning. The spray and burn technique is more effective because the herbicides used are translocated to defoliate and control residual vegetation before burning. Burning is delayed several months after spraying to achieve maximum root kill and stem desiccation.

DIRECT SEEDING

Direct seeding is an effective, rapid, and inexpensive regeneration alternative for shortleaf pine. But like other regeneration methods, it is not fail-safe. However, most recorded failures have been due to improper application techniques such as seeding on unsuitable sites, seeding out of season, inadequate site preparation, poor quality seed, and sowing too few or untreated seeds. Poor stand appraisal techniques also have classified some successful seedings as failures. Many failures can be avoided by following some simple guidelines. Since seeding and planting techniques differ so greatly, most aspects of direct seeding will be discussed in this section.

Condition of seedbed

Every site is different and must be judged on its individual merits before a prescription can be prepared. Generally, sites that can be planted can be seeded, but some conditions should be avoided:

1. Sites subject to heavy grazing unless grazing can be controlled the first 2 or 3 years.

2. Highly erodible soil and steep slopes where insufficient rough exists to hold the seed in place.

3. Thin, rocky soils or deep, upland sands that dry out rapidly after a rain, particularly those on south- and west-facing slopes.

There is one inviolate ground rule for direct seeding--seeds must be in contact with mineral soil. Seeds landing on surface litter, grass sod, or any other material besides mineral soil will not establish a seedling (Campbell 1982a, Russell and Mignery 1968).

Seed handling and protection

A prerequisite for direct seeding success is the use of good quality seeds that have been properly collected, stored, stratified, and treated with bird and rodent repellents. Minimum specifications for seedlots should be 95 percent purity and 80 percent germinative capacity. But even high quality seeds that have been properly stratified must be treated with bird and rodent repellents if the seeding is to be successful (Derr and Mann 1971). Heavy concentration of these seed predators can consume up to 5 pounds per acre of untreated seeds during the germinating period.

Few forest managers are equipped to collect cones and then extract, store, stratify, and treat seeds with repellents. The simplest procedure, especially for the small landowner, is to purchase seeds ready for sowing from a reputable seed dealer. Seeds should be purchased and a sowing contractor (if needed) engaged well in advance of the seeding operation. Seed delivery should be delayed until the time for sowing, however. Stratified and repellent-treated seeds should be held only about 2 weeks under cool conditions; air-conditioned facilities are advisable. If seeds are to be held longer than 2 weeks, they should be cold-stored between -3.8 and 4.5°C (Barnett and McLemore 1966). Storage below -3.8 degrees will damage the water-saturated megagametophytes; if kept too long above 4.5 degrees, germination or spoilage is likely to occur.

Repellent-treated seeds are coated with thiram and endrin. Rates of chemical use and application techniques are clearly provided by Derr and Mann (1971). Both of the recommended chemicals are labelled for this use and are environmentally safe if guidelines are followed (Barnett et al. 1980). Endrin is toxic to humans and handlers should always wear rubber gloves and an approved toxic-dust mask. After handling treated seeds, even with rubber gloves, the hands and face should be washed thoroughly before eating, drinking, or smoking. Treated seeds are safe to handle when proper precautions are followed; otherwise they can be very dangerous.

Seeding methods

Broadcast seeding.--Small acreages are usually most economically seeded by hand. One person using a cyclone seeder on easy-walking terrain can cover up to 12 acres per day. Walking straight, carefully flagged lines will result in fairly uniform distribution of seeds. The seeder should be carefully calibrated for the sowing rate in use. On farm woodlands, seeds may be scattered by hand in a relatively uniform pattern.

Larger acreage is best seeded by aircraft, but equipment must be well calibrated for the sowing rate in use. On a calm day when everything goes well, a helicopter can seed up to 3,000 acres per day.

The major advantages of broadcast seeding are its speed and low cost. Major disadvantages are the lack of spacing and stand density control.

Row seeding. -- Row seeding may be preferred over broadcast sowing when the landowner wants better control over spacing and density, or wants his trees in rows for mechanical harvesting. On a well-prepared site the seeds can be dropped by hand as one walks a furrow, row, or line. Seeds should be spaced one or two feet apart within the row. A common recommendation for spacing between rows is 10 feet.

Spot seeding.--Spot seeding is just what the name implies: dropping a predetermined number of seeds on a small spot. It offers the same spacing control as that of planted nursery seedlings, but is the slowest and most labor-intensive of the three sowing methods. However, spot seeding is the most highly recommended method for the small landowner who can do the work in his spare time with a minimum of tools and equipment, and who must minimize out-of-pocket expenses.

When the site has been properly prepared and mineral soil is exposed, three to five seeds should be dropped in a cluster (Phares and Liming 1961a). If surface litter or grass sod still occupies the site a spot should be cleared with the foot, a hoe, firerake, or other means to bare mineral soil. The seeds are dropped and pressed into the soil surface with a foot. On drier sites or sloping terrain it may be beneficial to cover the seeds with a layer of soil not to exceed 1 cm deep.

Sowing 3 to 5 seeds per spot is recommended to ensure stocking on most all spots. However, 2 or more seeds will germinate on many spots and result in a cluster of seedlings. Such multiple-stocked spots should be thinned back to a single seedling at age 2 or 3 years. Clustered seedlings on a spot cause a significant reduction in height and diameter growth by age 15 years (Campbell 1983).

Time and rate of sowing

Shortleaf pine seeds can be successfully sown from December 1 to April 1. Some of the best results have been obtained by sowing in December, January, or February, using unstratified repellent-treated seed (Seidel and Wilson 1965, Phares and Liming 1961b). Weathering will reduce the effectiveness of the repellent coating. Any seeds that are sown in the spring (after about March) must be stratified to obtain prompt and uniform germination. The change from dry to stratified seeds should be made 2 to 4 weeks before the average date of the last killing frost (Russell 1979). The length of stratification most appropriate for direct seeding of shortleaf pine seeds is about 60 days (Seidel 1963, Barnett and McGilvray 1971). Freshly collected lots are generally less dormant than stored ones.

The key to a proper sowing rate is an adequate number of sound, germinable seeds per acre. We recommend 18,000 broadcast, 10,800 row seeded, and 7,200 spot seeded. However, broadcast sowing rates are usually developed on a weight basis, so the number of seeds per pound must be determined for each separate lot. Seeds per pound vary greatly from year-to-year and from lot-to-lot; shortleaf seeds may range from 32,000 to 73,000 per pound, so an accurate seed count is needed for each operation.

Once the number of seeds per pound has been determined, seed germinability must be considered. If a seed lot averages 45,000 per pound, and germination tests average 88 percent, then that lot has only 39,600 germinable seeds per pound. Stratification and repellents add about 15 percent to the weight.

Recommended uses of direct seeding

Although direct seeding is not widely used to regenerate shortleaf pine, it does meet several reforestation objectives. Seeding is an excellent technique for landowners to inexpensively regenerate small acreages. Seeding has also been used to quickly reforest large acreages ruined by wildfires in the Ouachita Mountains. Clearly, direct seeding will continue to be used to meet these special needs. However, general interest in direct seeding has decreased due to the lack of control of tree spacing and due to failures under unfavorable climatic conditions. Furthermore, direct seeding does not efficiently utilize genetically improved seeds because the process uses many seeds to establish one seedling.

PLANTING CONTAINER SEEDLINGS

Many aspects of planting container seedlings are the same as those for bare-root stock. However, there are some important differences. Despite their bulk and weight, container seedlings are attractive because of planting ease. The uniformly shaped root systems of container seedlings are easily planted by hand or machine.

Hand planting

Container seedlings can be hand planted using conventional bare-root planting tools or tools designed for specific container types. Such special tools have been used to plant container stock at twice the rate of hand planting bare-root stock (Appelroth 1971). These planters work by displacing or dibbling the soil to make room for the seedling root ball. Their effectiveness depends greatly on the soil type and soil moisture, and they work well on mid-range soil types such as sandy loam, loam, and silt loam. For clay soils, tools must be designed to avoid soil compression or case hardening of the side walls when the hole is opened. For very sandy soils the tool must prevent the side walls from caving in before the seedling can be properly planted. Hand-held power augers can be used for planting stock grown in very large containers.

Removing a soil core having the same configuration as the container seedling plug before planting results in better seedling performance in heavy soils or compacted soils. In Louisiana, loblolly pine seedlings planted in a heavy silt loam soil survived better after 18 months when a core was removed rather than when a dibbled hole was made (Barnett and Brissette 1986).

Mechanical Planting

Most mechanical planters designed for bare-root seedlings can be adapted for planting container stock with only minor modifications. Conventional planting machines are either of the continuous furrow type or the intermittent furrow type and are usually fed manually. Modifications for container seedlings may only require changes in operator technique on continuous furrow machines, while intermittent planters may need some changes to the seedling holding mechanisms.

Depth of Planting

As with bare-root stock, planting container-grown seedlings to the proper depth is important to ensure good survival and growth. Container seedlings should be planted deep enough to allow covering the top of the root plug with about 1.25 cm of soil. Covering the container reduces drying in the root zone caused by the wicking effect of the media or planted container. Planting below the groundline also reduces the chance of frost heaving of fall- or winter-planted container stock.

PLANTING BARE-ROOT SEEDLINGS

Shortleaf pine planting procedures are basically the same as those for any southern pine species. Detailed instruction is available in Planting the Southern Pines (Wakeley 1954), which remains the most complete guide available. Limstrom (1963) offers additional information applicable to planting shortleaf pine in the central and northern portions of its range. Key requirements for planting shortleaf are selection of a suitable site, use of the best seedling quality and planting technology, and adequate control of competing vegetation.

Drought is probably the most widespread cause of the low initial survival (Wakeley 1954). Probably the greatest loss of planted pine seedlings occurs when they have not re-established good soil-root contact within 5 days after planting. Failure to make contact may result from poor planting, low initial soil moisture, prolonged rainfall deficiency following planting, and seedling quality. We can improve on poor planting, but the other variables require an understanding of seedling and environmental characteristics.

There is a period of time, termed a "planting window", in which the probability of seedling establishment is quite high. The size of the window varies from year to year, depending on environmental factors; within any one year it varies with nursery management and seedling care. Seedling dormancy and moisture level at the planting site are particularly important in defining duration of the window opening.

The safest time to plant seedlings is late winter and early spring, after most of the severe winter weather has passed. From mid-February through March is usually the ideal time to plant. This is based on many studies we have done comparing survival of seedlings planted from early December through May. Two reasons explain why survival is usually best from late winter and early spring plantings. First, weather conditions are generally more favorable. With early planting, in December and January, the danger is cold weather. When the ground is frozen, roots cannot take up moisture. If at the same time seedling tops are exposed to strong winds, they dry out. The problem is desiccation rather than outright freeze damage. On heavy textured soils that have been mechanically prepared, frost heaving may also be a problem. Winters vary considerably, and survival from early planting during mild winters can be as good as survival from March planting. An advantage of early planting, when it is followed by a winter mild enough to permit good survival, is that the seedlings start growing earlier in the spring and, therefore, make better growth.

With late planting, in April and May, the danger is that a drought may occur before the seedlings can become established. Also, when planting is done in April or May, some of the growing season has already passed, and grass, weeds, and hardwood brush have gained an advantage on the seedlings. Consequently, late planted seedlings do not grow as well as seedlings planted in February or March.

Second, pine seedlings reach a physiological peak in March just prior to breaking dormancy. A low level of photosynthesis takes place in the seedbeds during the winter whenever the weather is favorable, and the food produced is transported to and stored in the roots. The more stored food in the roots, the better chance a seedling has to quickly initiate new root growth after it is planted.

A rather common reason for poor survival is root desiccation between the time the seedlings are removed from the package and actually planted. A healthy seedling placed into a dry planting machine box quickly loses its ability to survive. Exposure of fine rootlets to desiccating conditions predisposes the seedling to severe shock, slow recovery, or death. Ideally the moisture film covering the roots should never be allowed to evaporate, but drying for 10 or 15 minutes may be acceptable on overcast days. Many nurseries coat the seedling roots with a clay slurry to retard moisture loss. Alternatively, the seedlings may be dipped in highly absorbent organic gelatinous materials, but these materials' ability to increase shortleaf pine survival has not been rigorously tested.

Planting instructions often caution that J-rooting and other root malformation is to be avoided, but there is little conclusive evidence that malformed root systems are detrimental to survival. A planting slit that is too shallow results in root deformation, but the real cause of mortality is probably shallow planting.

RELATING NURSERY PROCEDURES TO FIELD PERFORMANCE

Seedling Quality

In recent years planting stock quality has received considerable attention. A IUFRO workshop entitled "Techniques for Evaluating Planting Stock Quality" was held in New Zealand in 1979 and subsequently an issue of the New Zealand Journal of Forestry Science (Vol 10, number 1) served as a proceedings of that meeting. In 1984 another workshop, entitled "Evaluating Seedling Quality: Principles, Procedures, and Predictive Abilities of Major Tests," was held at Oregon State University. A proceedings of that meeting was also published (Duryea 1985). The level of interest in this topic reflects the biological, economical, and managerial importances of getting plantations off to a good start.

To foresters, the ultimate measure of seedling quality is field performance. When defined in terms of field performance, stock quality is a function of the seedlings' potential to survive and grow after outplanting. Seedling quality represents a complex integration of physiological and morphological characteristics and, therefore, cannot be measured easily. Also, stock quality must be defined for a specific point in time, because subsequent handling, storage, or planting can have a tremendous impact on potential field performance.

Attributes of seedling quality can be grouped into 2 categories, material attributes and performance attributes (Ritchie 1984). Material attributes are directly measurable morphological or physiological characteristics such as root collar diameter, dry weight, foliar nutrient content, and plant moisture stress. Wakeley's (1954) morphological grading standards for southern pines fall into this category. When several material attributes are considered together they can be useful for describing potential field performance. Individually, however, these attributes have little predictive value unless they are well outside the normal range, such as pine seedlings with very small (< 3 mm) root collar diameters.

Performance attributes are whole-seedling measures of response to particular test conditions. Examples include testing for root growth potential and cold hardiness. Such tests are good predictors of field performance. However, they often require 3-4 weeks to complete, and therefore the results are usually not timely enough to aid in making management decisions. Performance attribute testing is extremely valuable, however, when used to evaluate nursery culture and then apply the results toward improving future crops.

High quality shortleaf pine seedlings can be grown as either bare-root or container stock. For either type of stock, morphological characteristics have been used to define seedling quality. The most widely accepted standards for describing southern pine bare-root stock are Wakeley's (1954) morphological grades. These grades emphasize root collar diameter and classify as cull any shortleaf pine seedling with a ground line diameter of less than 3 mm (Table 1). Recognizing the effect that the basal crook can have on root collar diameter, Chapman (1948) recommended a diameter of 2.5 mm at 2.5 cm above the ground line as the lower limit of plantable shortleaf pine seedlings. Similar standards have not been developed for containerized shortleaf pine.

Wakeley's morphological grades were developed after years of observing the survival and growth of seedlings that had various morphological characteristics when they were planted. In general, the distinction between plantable and cull seedlings is substantiated by outplanting success. However, there are enough exceptions that Wakeley (1949) recommended the development and adoption of physiological grades which better reflect survival and growth potential. He suggested measuring such physiological attributes as nutrient content, stored food reserves, and seedling water status. Since Wakeley's time, much progress has been made in the physiological evaluation of planting stock, with root growth potential receiving most of the attention (Stone 1955, Stone and Jenkinson 1971, Burdett 1979, Ritchie 1985). None of this important work has been done with shortleaf pine. The authors of this paper are currently evaluating several material and performance attributes of shortleaf pine as a means of relating nursery cultural techniques to field performance.

Although morphological grades have limitations, they have provided valuable insights into the importance of seedling quality. For his grading study, Chapman (1948) established shortleaf pine plantations on relatively poor quality, old field sites in southern Indiana and southern Missouri. Clark and Phares (1961) measured these plantations at age 19-21 and found, depending on the site, that the large seedlings (20-30 cm tall and 5 mm diameter at 2.5 cm) produced from 31 to 92 percent more volume per hectare than the small seedlings (10-20 cm tall and 2.5 mm diameter). Much of the increased

Table 1.--Specifications of morphological grades[1/] of uninjured[2/] 1-year-old shortleaf pine seedlings (Wakeley 1954)

Grade	heights	Root collar diameter	Nature of stem	Bark on stem	Needles	Winter buds
	(cm)	(mm)				
1	10-25	About 4.8	Stiff, woody. Usually a crook at ground level; often branching	Usually on entire stem	Almost entirely in 3's and 2's	Usually present
2	7.5-15 sometimes 20	About 3.2	Moderately stiff; often with crook and branches	On lower part at least; often all over	Part at least 3's and 2's	Occasionally present
3	Usually less than 10	Distinctly less than 3.2	Weak; often juicy; often straight	Often lacking	Practically all single, bluish	Practically never present

1/ Grades 1 and 2 usually considered plantable, and grade 3 culled.

2/ Any seedlings with roots less than 12.5 cm long should be considered as grade 3 (culls), regardless of the quality of the tops.

volume was due to better survival of the larger seedlings. Although the large seedlings grew tallest during the first 3-5 years, by age 19-21 no longer did significant height differences existed. The large seedlings had significantly greater d.b.h. at age 21 at the Indiana site but in Missouri there was no relationship between seedling size and d.b.h. at age 19-21. Based on their results Clark and Phares agreed with Chapman's minimum plantable shortleaf pine seedling of 10 cm tall and 2.5 mm at 2.5 cm. However, for best results they recommended planting seedlings at least 15 cm tall and 3.8 mm in diameter at 2.5 cm above the root collar.

In another study, shortleaf pine seedlings selected from 3 nurseries over a 4-year period on the basis of height only were compared at age 9-12 for survival, height, d.b.h., and volume per tree (Grigsby 1975). The study included 289 trials of small (9 cm tall), average (18 cm), and large (30 cm) seedlings planted at 5 locations in southern Arkansas and northern Louisiana. With data combined across ages and sites no differences were found in survival; but the large seedlings were significantly better than the small seedlings in height, d.b.h., and volume, and also had significantly greater volume than the average seedlings.

Similar results from planting large shortleaf pine seedlings have been shown for container-grown stock. In a mycorrhizae study planted on 2 sites on the Ouachita National Forest, large container stock (18 cm tall and 2.5 mm root collar diameter) performed better than small containerized seedlings (10 cm tall and 1.8 mm diameter) on one of the sites (Ruehle and others 1981). On the site with differences, non-innoculated large seedlings had significantly larger root collar diameters and individual volumes than small non-innoculated seedlings 2 years after planting. There were no differences in survival or height. There was dense, overtopping competition to the planted pines on the site where no significant differences were measured.

Large container seedlings were significantly taller than small container stock 28 months after planting in central Louisiana (Barnett 1982). Significant correlation coefficients were obtained between field height at 28 months and seedling height, top and root fresh weights prior to outplanting. Both studies indicate that seedling size has more effect on growth than on survival with container stock. Apparently the intact root systems of containerized seedlings result in good survival over a wider range of seedling size than with bare-root stock.

Developing a Target Shortleaf Pine Seedling

Based on past research and years of observing planting results by field foresters, a shortleaf pine seedling ideotype-or target seedling-can be described. The concept of a target seedling should include the acceptable range for each attribute and be flexible so that it reflects the current state of knowledge. As more evidence is accumulated the target specifications should change. It must also be recognized that different target seedlings may be appropriate for different geographic locations or site characteristics.

The value of a target seedling is that it provides a goal for the nursery manager to work towards and a standard of comparison for the forester.

In December 1984, a group of 19 USDA Forest Service, industry, state, and university foresters and silvicultural researchers met to discuss ways to improve artificial regeneration success with shortleaf pine in the Ouachita and Ozark Mountains. As a result of discussions at that meeting an initial target seedling was defined based on morphological charateristics (Table 2). Material physiological attributes and performance attributes were not included because they have not been investigated in shortleaf pine. The meeting did set a research agenda that addresses other attributes and as results become available the target seedling specifications will be refined and expanded.

PRODUCING SEEDLINGS OF DESIRED QUALITY

Seed Quality

The goal of the seedling producer is to grow as large a percentage of the crop as possible to target seedling specifications. The more uniform the crop, the easier it is to bring the greatest number to the desired quality. Crop uniformity requires sowing high viability seed lots. Seed viability can be markedly reduced by poor extraction, processing, or storage practices. In early studies which included shortleaf pine, Huberman (1940a) determined that the sum of all losses following germination was not nearly as great as the number of seeds that failed to germinate. Because laboratory germination was similar, he concluded that the problem was due to faulty extraction or storage. Modern methods and equipment make it possible to process and store pine seeds while maintaining high viability (Krugman and Jenkinson 1974).

The seeds that Huberman (1940a) used were not stratified. Shortleaf pine seeds exhibit dormancy and need stratification for rapid, uniform germination. Stratification for 56-70 days proved best when both speed and completeness of germination

Table 2.--Initial target seedling specifications for bare-root shortleaf pine seedlings to be planted on Ouachita and Ozark Mountain sites

Attribute	Specifications
Height	15-25 cm
Root collar diameter	2.5-5.0 mm
Root/Shoot ratio (ODWT)	0.40
Foliage	Mostly secondary needles
Stem	Woody
Terminal bud	Well developed by November 1
Root system	$\geq$ 7 laterals, fibrous, mycorrhizal
Tap root	10-20 cm long

were considered over a range of stratification durations (Barnett and McGilvray 1971). Clearly then, uniform establishment in the nursery or in containers requires careful seed extraction and cleaning, followed by proper storage and then stratification for about 60 days before sowing.

Sowing regimes and seedbed density

To grow a crop of seedlings to target specifications requires a thorough knowledge of how those seedlings grow and respond to cultural manipulation. In a bare-root nursery, the first considerations are sowing date and seedbed density. After comparing several sowing dates from March to early May in central Louisiana over a 2-year period, Huberman (1940b) recommended sowing shortleaf pine before mid-April. Based on operational observations, TVA sowed shortleaf pine in March and early April at its nurseries in east Tennessee and northwest Alabama (TVA 1954).

Seedbed density has a tremendous impact on seedling morphology, especially stem diameter and root mass. With loblolly and slash pines, average root collar diameter decreases with increasing density (Shoulders 1961). In loblolly pine, as density increases root weight is reduced proportionately more than shoot weight, resulting in a corresponding decrease in root to shoot ratio (Harms and Langdon 1977). Wakeley (1954) stated the maximum density for shortleaf pine was 540-590 seedlings per square meter. However, he also wrote that under favorable nursery conditions such densities would result in about 20 percent cull seedlings. Based on the results of his grading study, Chapman (1948) recommended a maximum of only 270 seedlings per square meter. Considering the value of seed orchard seed and the current cost of labor for culling nursery stock, a density near Chapman's recommendation is more appropriate.

Seedling Growth and Development

Once seedlings become established in the nursery, they enter a rapid growth phase. In this phase the nursery manager encourages growth by maintaining adequate levels of soil moisture, by addition of nitrogen fertilizers, and by pest management procedures such as weed and disease control.

As seedlings approach the target height, cultural treatments are usually applied to limit shoot growth. Water and topdressing with nitrogen are withheld to induce sufficient stress to stop shoot elongation. Often stress alone will not halt height growth. Single or repeated undercutting of the seedlings has significantly reduced shoot growth, markedly increased lateral root development, and improved field survival of loblolly pine (Tanaka and others 1976). While stress can effectively control seedling height, too much stress will also limit diameter growth. Therefore careful monitoring of the crop is necessary to ensure that the level of stress applied will stop elongation without severely limiting diameter development.

Cultural treatments that work for loblolly pine are usually applied to shortleaf pine as well. However, the two species grow differently in the nursery. Shortleaf pine tends to develop more slowly early in the growing season, but also tends to grow longer into the fall and early winter than loblolly pine (Huberman 1940b). Nursery growth and the effects of nursery culture on field performance of shortleaf pine are currently under investigation by the authors.

Lifting

After high quality stock is produced, careful lifting and handling are essential to ensure good survival and growth after outplanting. Because shortleaf pine may not have as good storage potential as loblolly pine (Venator 1985), lifting schedules need to be closely coordinated with planting needs so that storage time can be minimized. Throughout lifting, handling, and storage operations, seedling roots must be protected from drying exposure, heat, extreme cold (freezing), and mechanical damage.

CARE OF PLANTING STOCK

Storage

Specific guidelines for the timing of lifting and length of time in storage for shortleaf pine genotypes will not be available until further research has been completed. Parallels can be drawn from research of loblolly pine. However, this must be done carefully since the timing of the dormancy cycle appears to be later in shortleaf than in loblolly. That is, shortleaf is later in forming a winter bud and survival potential is maximal from late December to early March (Wakeley 1954). In loblolly pine, root growth potential (RGP) increases as the seedlings are chilled by winter temperatures (0-8°C). However, storage of trees lifted too early causes a rapid decline in RGP (Carlson 1985). Until research specific to shortleaf pine can be completed, it is advisable to delay lifting shortleaf seedlings until late December and to complete that operation by March 1.

In general, storage time should be a maximum of 3 weeks after lifting. However, in one specific study, survival of shortleaf pine seedlings lifted in January and February dropped 36 percentage points following storage for 30 days while seedlings lifted in December stored well (Venator 1985). If seedlings are still in the nursery bed when bud break occurs, then storage time should be reduced to 1 week. These guidelines are very generalized but must remain speculative until research specific to shortleaf genotypes is completed. Storage of planting stock should be at 1-3°C in high humidity conditions. Planting stock must not be allowed to freeze since this reduces survival potential substantially (Bean 1963).

Freshly lifted seedlings should be kept in shaded, cool and moist conditions throughout the grading and packing operation. Seedling root systems should be coated with clay slurry to reduce desiccation in storage and handling. Packaging can be done in open ended U. S. Forest Serivce (USFS) bundles or in closed containers such as Kraft-Polyethylene (KP) bags or boxes. Packaging in bundles creates a need for watering each bundle in storage about every 3 days. Care must be taken to allow watered bundles to drain excess water since souring can occur when seedlings are under flooded conditions in storage. Bundles may be preferred over enclosed containers if cold storage is not available after seedlings leave the nursery. If cold storage is available, then enclosed containers provide high quality and less labor-intensive storage.

Transporting and Handling

Transportation should be via refrigerated van (1-3°C) from the nursery cold storage facility to a regional cold storage facility. Planting contractors should obtain seedlings from this facility on a daily basis. If regional cold storage facilities are not available, and distance from nursery to planting site is relatively short, then planting contractors should pick up seedlings daily from the nursery. If this is not feasible, then USFS bundles should be used and regional storage should be set up in a cool, shaded building protected from freezing, and with a water supply available. Delivery of stock to the planting site should be in a covered vehicle, preferably insulated against solar warming. If seedlings are stored on site outside this vehicle, then they should be protected from direct sunlight and from freezing.

Seedling handling on the planting site should be minimized. Seedlings should not be root pruned or counted under field conditions, since this will result in abnormally long exposure to desiccation. If such activities appear to be necessary then the nursery should be asked to do such work prior to shipment of the seedlings.

Container seedlings should be treated as described for bareroot stock if they are removed from the containers and shipped as plugs. If seedlings are shipped in the containers, then when they arrive at regional storage they should be removed from cartons, rewatered, and kept under shaded conditons. If cold storage is available then container seedlings can be placed in storage in the packing boxes.

PLANTING SPACING

The relationship between seedling planting spacing and stocking levels in the established stand is heavily dependent on seedling quality. If seedling survival can be predicted to be high, the number of seedlings planted per acre can be reduced to the point where precommercial thinning is not necessary. It is therefore apparent that high quality planting stock can play a major role in reducing not only regeneration costs but also the cost of later silvicultural activities. It follows that one can pay a premium price for such stock and reap considerable returns throughout the rotation (Venator 1981). Current planting spacing varies from 8 X 8 ft. to 10 X 10 ft. (681 and 436 seedlings per acre, respectively), depending largely on the confidence the forester has in attaining high survival.

EVALUATION OF PLANTING SUCCESS

An important aspect of regeneration is evaluation of whether the planting or direct seeding was a success. A walk through the area is not an adequate evaluation technique. The most reliable means of evaluation is to randomly select areas to be sampled sometime after the planting is completed. Terry (1983) suggests establishing twenty 1/100-acre plots on a grid on each tract in March or April following planting. Mark the center of each plot with a stake, locate the plot on a map and flag each planted seedling. In the fall after grass has died, return to the plot and count the surviving seedlings.

If at least 350 well-distributed seedlings per acre survive, it probably will not pay to replant. When first-year stocking is unsatisfactory it is often best to burn the area and replant. Most interplanting efforts result in suppressed seedlings. If compelled to interplant, do not plant within 20 feet of established seedlings.

Campbell (1982b) provides a detailed description of how to make inventories of direct seeded stands. A critical evaluation is necessary. Many direct seedings have been misjudged as failures simply because the evaluators did not locate small seedlings in a grass rough. Also, anytime direct seeding is used, some thought should be given to the potential need for precommercial thinning (Lohrey 1972).

When checking survival, evaluation should be made for other problems that may exist--i.e., disease or insect infestations, or need for release from competing hardwoods. Plantations that survive the first year may be lost if needed corrective action is not taken.

SUMMARY

The goal of reforestation should be to plant seedlings of the best genetic and physiological quality available for the site. This requires teamwork between the nursery manager and silviculturist. Nursery practices which have major impacts on seedling quality include soil management, seedbed density, control and protection of seedling development, and timing and methods of lifting. Between lifting and planting, a cool moist environment is essential to maintain stock quality. Seedlings must be protected from heat, desiccation, and freezing during handling, storage, and transportation, and at the planting site.

The ultimate measure of seedling quality is field performance. Silviculturists and nursery managers need to be able to predict seedling performance based on characteristics that can be measured. Conventional morphological traits used to grade seedlings have provided some quality control, but an ability to assess physiological condition would provide a key to accurate prediction of nursery stock performance. Although several techniques have potential, an easy, reliable method for determining physiological quality of shortleaf pine seedlings is needed.

Direct seeding offers optional techniques highly suited to small landowners and for special situations such as reforestation following wildfires.

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PROCEEDINGS

of

Symposium on the Shortleaf Pine Ecosystem

LITTLE ROCK, ARKANSAS

MARCH 31 - APRIL 2, 1986

Edited by

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Southern Forest Experiment Station
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Symposium on the Shortleaf Pine Ecosystem

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