Forestry and Wildlife
Research Series No. 1

Alabama Agricultural
Experiment Station
Luther Waters, Jr. Director
Auburn University
Auburn, Alabama

October 2000

Planting Morphologically Improved Pine Seedlings to Increase Survival and Growth

Table of Contents

COVER PHOTO: Demonstration plots installed by Doug Sharp at a nursery in Brewton, Alabama. Both seedlings were planted on January 5, 1994. Photos, taken on September 13, 1994, show the difference in early growth. No chemical weed control was provided.

Due to the merger of the School of Forestry and the Department of Wildlife Sciences, the School of Forestry series has been replaced by the Forestry and Wildlife Research Series.

Planting Morphologically Improved Pine Seedlings to Increase Survival and Growth

David B. South[1]

INTRODUCTION

Loblolly pine seedlings used by most researchers and landowners are commonly grown at high seedbed densities (more than 25 plants per square foot of growing area). These seedlings are classified as Grade 2 seedlings (Table 1) and typically have a root-collar diameter (RCD) that averages 4 millimeters (mm). Since these seedlings have small roots, survival under less-than-ideal conditions can be a problem. As a result, landowners and researchers in the South typically overplant to ensure adequate survival. Researchers sometimes double-plant (planting two seedlings per spot) in order to ensure one seedling lives. Researchers and landowners could also increase survival rates by planting large-diameter seedlings (morphologically improved seedlings), which have been grown at low seedbed densities (less than 20 plants per square foot).

In the southern United States, seedlings of longleaf pine and various hardwood species are commonly grown at low seedbed densities (less than 10 plants per square foot) to increase their field performance. However, the trend of lowering the seedbed density for loblolly and slash pine has been slow to occur. The primary reason for this has been a lack of demand for morphologically improved seedlings of these species. Many landowners do not request seedlings grown at low seedbed densities because they haven't been informed about the benefits of using these plants. In fact, many landowners have been told that seedling morphology is a poor indicator of seedling performance.

Some of those who say that seedling morphology is a poor predictor of survival cite studies conducted in the 1930s when seedbed densities were high. Others cite more recent studies that used seedlings from seedbeds with densities greater than 45 plants per square foot (Dierauf et al. 1993). Some studies confound seedling morphology with other factors that affect survival. Although several studies show positive correlations between RCD and

TABLE 1. DEFINITIONS OF SEEDLING TERMS FOR BARE-ROOT LOBLOLLY PINE

Term	Definition
Cull seedling	An unacceptable seedling that does not meet a certain size standard [e.g. has a root collar diameter (RCD) less than 3 mm]
Plantable seedling	A seedling that is slightly larger than a cull. Typically has a RCD of 3 mm or more
Grade 2 seedling	A seedling that has a RCD ranging from 3.2 to 4.7 mm. This seedling size is desired by most tree planters
Grade 1 seedling	A seedling that has a RCD greater than 4.7 mm
Regular seedling	The average loblolly pine seedling planted by most researchers in the South. Typically has an average RCD of about 3.9 mm
Target seedling	The seedling that the nursery manager would produce the most of under ideal weather conditions. The target seedling at certain industry nurseries is much larger than at others
Morphologically improved	The seedling is only grown at low seedbed densities ($< 20/ft^2$) and at least half of the population has RCDs greater than 5 mm and none less than 3 mm). This seedling has a higher root-weight ratio and has been cultured to give more fibrous roots, but is not taller than regular seedlings
Optimum seedling	The seedling size that will minimize overall reforestation costs while achieving established goals for initial survival and growth. Although the size of this seedling has not been defined, it might have a RCD of about 8-10 mm

[1]*South is a Professor in the Auburn University School of Forestry and Wildlife Sciences.*

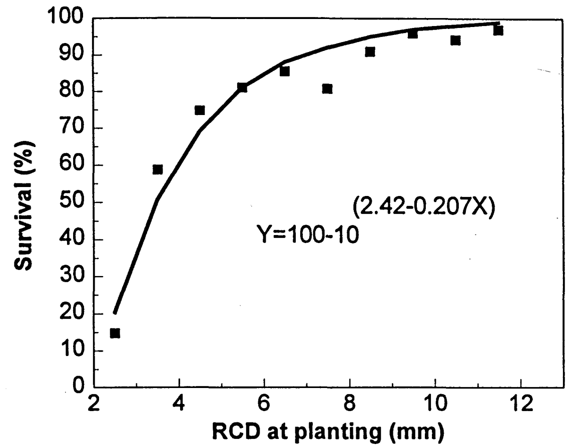
survival (Dierauf et al. 1993; South 1993; McGrath and Duryea 1994), these studies are usually not cited by those who claim that seedling morphology is a poor predictor of field survival.

The general pattern, observed over the last 50 years, however, has been that when large-diameter (morphologically improved) seedlings are properly planted, they typically survive better than smaller seedlings (South 1993). Although all sites will not show this relationship, one site in Georgia illustrates the relationship between RCD at planting and seedling survival (Figure 1).

Some forestry companies agree. Their leaders believe that seedling performance is related to RCD and that with proper lifting and planting, seedlings with large diameters tend to survive and grow better than small-diameter seedlings (Autry 1972; McGrath and Duryea 1994; South 1993). As a result, the target seedling RCD for some companies is 6 mm (or greater); this is about 2 mm larger than seedlings used by most researchers (Table 2).

The practice of growing pine seedlings at low seedbed densities has been used throughout the world to improve the performance potential of pine seedlings. For example, since the early 1970s, slash pine and loblolly pine seedlings have been grown in bare-root nurseries in South Africa at densities of 12 to 15 seedlings per square foot. Likewise, for more than 20 years, nurseries in New Zealand have been growing Monterey pine seedlings at low seedbed densities. In fact, the recommended spacing varies with site. For sites with low elevation, densities of 15 seedlings per square foot are used; for more adverse, high-elevation sites, lower densities (12 seedlings per square foot) are recommended (FRI 1988). Currently, the ideal size of a pine seedling in New Zealand is about 6 to 12 mm in diameter at the root collar (MacLaren 1993).

Figure 1. Relationship between seedling survival and root-collar diameter at planting and survival (South and Mitchell 1999).



While seedling morphology is not a **perfect** predictor of field **survival,** it is about the best tool available to separate individual seedlings prior to planting according to their potential for **growth.** This is much like the case of genetically improved seedlings. Although knowing the genotype usually does not help predict field **survival,**

TABLE 2. THE GROUNDLINE DIAMETER[1] OR ROOT-COLLAR DIAMETER OF REGULAR BARE-ROOT LOBLOLLY PINE SEEDLINGS USED IN RESEARCH STUDIES

State	GLD[2] *mm*	Study	State	RCD[3] *mm*	Study
			GA	3.0	Sung et al. 1997
GA	2.8	Miller et al. 1995	GA	4.0	Harrington and Howell 1998
GA	3.0	Miller et al. 1995	GA	3.7	Kormanik et al. 1995
MS	3.0	Miller et al. 1995	GA	4.4	Kormanik et al. 1995
AL	3.0	Miller et al. 1995	SC	5.0	Barnard et al. 1997
LA	2.5	Miller et al. 1995	SC	4.2	Barnard et al. 1997
LA	3.6	Miller et al. 1995	SC	3.5	Barnett and McGilvary 1993
AL	3.6	Miller et al. 1995	SC	3.7	Barnett and McGilvary 1993
AR	3.6	Miller et al. 1995	SC	3.6	Cram et al. 1997
TN	4.3	Miller et al. 1995	SC	4.1	Cram et al. 1997
LA	4.1	Miller et al. 1995	SC	3.3	Cram et al. 1997
AL	3.0	Miller et al. 1995	SC	3.6	Cram et al. 1997
GA	2.8	Miller et al. 1995	SC	3.7	Cram et al. 1997
VA	2.8	Miller et al. 1995	SC	4.3	Cram et al. 1997
VA	3.1	South et al. 1995	SC	4.3	Cram et al. 1997
AL	5.3	South et al. 1995	SC	4.2	Cram et al. 1997
Avg.	**3.4**		**Avg.**	**3.9**	

[1] Since seedlings are usually planted with the RCD below the groundline, the GLD is often measured at a higher point on the stem than the RCD. [2] GLD = groundline diameter. [3] RCD = root-collar diameter.

genetically improved seedlings are still planted to improve the **growth** potential of a stand. As with genetically improved seedlings, the main reason for using morphologically improved seedlings is to improve the growth potential of pine plantations.

FACTORS THAT INFLUENCE SEEDLING SURVIVAL

Initial survival in the field is affected by several factors, including, in order of importance, environment, handling, morphology, and physiology (Figure 2).

The most important factor is the environment where the seedling is planted (called the site environment). This includes such things as soil water content at time of planting, temperature and amount of rainfall soon after planting (a hard freeze or extended drought, for example), soil texture, soil depth, competition from weeds, number of insect pests, and amount of deer browse.

Seedling handling is also very important. The type of lifting machine, the amount of cold storage, the temperature of cold storage, the stripping of roots during lifting, the pruning and washing of roots after lifting, the depth of planting—all can affect survival. In some cases, the way the tree-planter handles the seedlings can make the difference between a plantation with 5% survival or 85% survival (Rowan 1987). In many years survival of machine-planted trees will be higher than for inadequately supervised hand-planted seedlings (South and Mitchell 1999b).

The next important factor is seedling morphology. This includes, for example, root-weight ratio, root mass, RCD, secondary foliage, and seedling height. In contrast, presence of a well-formed terminal bud is not important for survival.

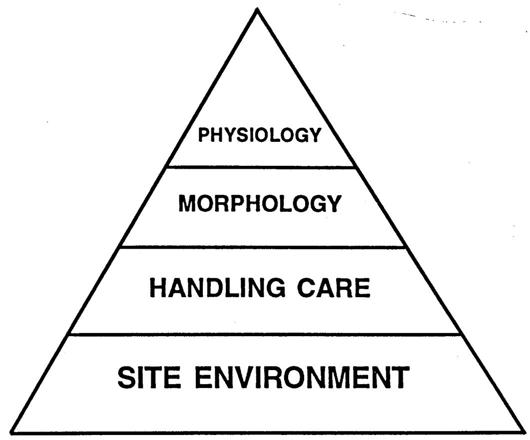
Seedling physiology is also important and can be influenced by the nursery environment (fertilizer regime, excessive rain, lack of soil oxygen, freezes, high temperatures, photoperiod, pathogens, cultural practices, toxic chemicals) as well as handling practices (condition of the seedlings at lifting, amount of cold storage, desiccation of roots, etc.). However, seedling physiology can be very difficult to evaluate on individual seedlings at the time of outplanting.

To a limited extent, the genetics of a seedling will affect initial survival (through its effects on both seedling physiology and seedling morphology). Although initial survival is usually high for many progeny tests, the heritability for survival can be 0.78 (NCSU 1995).

LOW SEEDBED DENSITIES

Seedlings grown at low seedbed densities usually survive better than seedlings grown at high seedbed densities. Seedlings grown at low seedbed densities have

Figure 2. A generalized model illustrating the relative importance of four factors affecting survival of transplanted pine seedlings. Any one factor can be the major cause of failure in a particular event.



stronger first order lateral roots, more short roots, more foliage, and a higher root-weight ratio (all part of a morphologically improved seedling).

Contrary to popular belief, top-pruned seedlings produced from low seedbed densities are usually no taller than seedlings grown at high seedbed densities. Proper top-pruning in the nursery increases the root-weight ratio and, therefore, increases the chance of survival when the site enviornment is less than optimum (South 1998).

Several studies have demonstrated better survival from seedlings grown at low seedbed densities (Table 3). When average survival is less than 90%, morphologi-

TABLE 3. INCREASE IN SEEDLING SURVIVAL BY USE OF LOBLOLLY PINE SEEDLINGS GROWN AT LOW SEEDBED DENSITIES

Study	Low density	Medium density	Survival gain
	no/sq ft		*percentage points*
Rowan 1986	15	30	14
Shoulders 1961	14	38	12
Shoulders 1961	10	30	9
Rowan 1986	15	30	8
Leach et al. 1986	20	30	4
Shoulders 1961	13	35	3
Rowan 1986	15	30	2
Shoulders 1961	12	31	1
Shipman 1964	20	40	1
Carneiro 1985	15	26	-3
Average			5

Multiple listings for Shoulders (1961) and Rowan (1986) due to multiple tests.

cally improved seedlings exhibit better survival than regular seedlings. Planting seedlings from low seedbed densities usually increased survival by 4 to 10 percentage points over that of seedlings grown at 30 plants per square foot. Research has shown, however, that seedbed density will have little or no effect on survival when average survival is greater than 96%.

Seedling height also has an effect on survival. When grown at high seedbed densities, shorter seedlings are more likely to survive than taller seedlings (Dierauf 1973; Tuttle et al. 1988; Sluder 1991; Hitch et al. 1996). For example, when grown at the same seedbed density, slash pine seedlings which are 7 inches tall may survive better (66% survival) than seedlings which are 13 inches tall (35% survival) (Bengtson 1963). In fact, very tall seedlings grown at high seedbed densities (which produce low root-weight ratios) survive pooly when planted on areas with limited moisture.

Root-weight Ratio

Although low seedbed densities will result in seedlings with higher root-weight ratios, it is very important that the root-weight ratio not be greatly decreased during the lifting process in the nursery. If nursery managers are not careful, injury to seedlings can result when using mechanical belt lifters (Green and Danley 2001). Less injury has been observed on seedlings when lifting is done by hand (Barnard 1980) or when a Fobro-type lifter is used to assist in hand-lifting.

A number of studies demonstrate the balance between roots and shoots is important to seedling survival, but some researchers have implied that a morphological trait (such as root-weight ratio) is not important for field survival. Apparently, these individuals still believe Wakeley (1954) who did not include a shoot/root ratio along with his seedling grades. Wakeley believed such ratios had "... never proven useful in grading southern pine nursery seedlings ...." Perhaps Wakeley was comparing the length of the shoot with the length of the taproot (an invalid measure of shoot/root ratio).

The balance between root mass and shoot mass is especially important when seedlings are planted in areas or in seasons when moisture stress is likely to be severe. In fact, in cases where Grade 2 seedlings survived better than Grade 1 seedlings (Blair and Check 1974; Venator 1983), the lower survival may have simply been due to lower root-weight ratios.

Root Growth Potential

One reason that more roots improve survival is because the existing roots produce many new roots soon after planting (Williams et al. 1992). This ability is related to a seedling's root growth potential, which is a measure of the new root growth under controlled conditions. Theoretically, seedlings that produce many new roots within a few weeks of planting will survive better than seedlings which produce only a few new roots.

Some researchers believe seedling morphology has little to do with the ability of a seedling to quickly produce new roots. However, researchers have demonstrated a positive correlation between root biomass and root growth potential (Switzer 1962, Larsen and Boyer 1983, Carlson 1986). Apparently, the more fibrous lateral roots a seedling has, the more root-tips are available for new root growth. Seedlings which produce more new roots have a greater ability to take up more water (Carlson 1986).

Proper Planting Techniques

One tree planter stated, "I am a quality planter. I prune the roots to fit the planting hole." This type of mentality will result in pruning more roots from a large seedling than from a small seedling. And it may explain, in part, why some operational foresters have observed that Grade 1 seedlings do not survive as well as Grade 2 seedlings. It may also explain why the results from research studies can differ greatly from those of operational studies if unsupervised tree planters strip and prune roots prior to planting.

The survival benefits of growing seedlings at low seedbed densities will be destroyed if removing roots reduces the root-weight ratio (Wilder-Ayers and Toliver 1987). And the root growth potential of seedlings can be reduced in half by the single act of stripping the roots through a closed fist (South and Stumpff 1990). Without a doubt, pruning roots decreases survival (Harrington and Howell 1998). One way to reduce the likelihood of root pruning is to have seedlings planted with machines (South and Mitchell 1999b).

If seedlings with large root systems are planted too shallow (usually because the planting hole is too small), they will not survive well (South 1999). However, when planted deep enough (either by machine or by using proper hand-planting methods), seedlings with better root-weight ratios and more intact fibrous roots will survive better than seedlings which have less roots, less foliage, and lower root-weight ratios (often a result of being grown at high seedbed densities).

GROWTH OF MORPHOLOGICALLY IMPROVED SEEDLINGS

Although proper planting of morphologically improved seedlings can increase survival, the greatest and most consistent benefit of planting morphologically improved seedlings is an increase in growth (Table 4). In no case, did Grade 1 seedlings grow less (on an individual tree basis) than the Grade 2 seedlings. Lower per acre production was attributable only to poorer survival, which is likely a result of poorer root-weight ratios, taller seedlings, or inexperience in planting larger stock.

Increases in per acre volume gains can be made at ages 10 to 15 by planting seedlings with large RCDs usually because these seedlings have better survival due to higher root-weight ratios. In most cases, gains will result from both better survival and better average tree growth.

PREDICTING PER ACRE VOLUME GAINS

It is not enough to be able to say "if you want more wood, carefully raise and carefully plant stock with large diameters and root mass." What the practical forester needs is an estimate of the expected volume gain. Estimates of volume gain per millimeter increase in seedling diameter have been calculated for the examples in Table 4.

For example, if we assume the average RCD for a Grade 2 seedling is 4 mm and we assume the average for a Grade 1 seedling is 6 mm, then we can divide the volume difference by two to get an estimate of the volume gain per mm. If we exclude the 30-year row-plot data in Table 4, the average gain in volume amounts to about 190 cubic feet per mm. This suggests that, on average, stands 15 to 20 years old will have an extra 380 cubic feet per acre if planted with 6 mm seedlings (as opposed to 4 mm seedlings). Without making any further assumptions, this 380 cubic feet value may be the best way to forecast volume gains from planting large seedlings. However, this single value does not take site quality or age into account. The question now is how to predict volume gains for various ages and sites.

Percent Gain

There are several ways to estimate future volume gains. Geneticists sometimes predict the per acre volume gains by calculating a percentage of the volume expected from a local, unimproved source. A 12% gain in volume per acre might be estimated for first generation seedlings (from a rogued orchard) and a 30% gain in volume might be estimated for rouged second generation orchards.

Although this is a tempting method to use due to its simplicity, it can mislead the public since the percent gain varies with age. The percent gain in per acre volume observed at age eight will not be the same as that for unthinned plantations at ages 25, 30, 40, 50, etc. Therefore, not only is it important to tell at what age the predictions are valid, it is also important to know that the percentage gain varies with stand age.

TABLE 4. EFFECT OF A 1 MM INCREASE IN ROOT-COLLAR DIAMETER ON GAINS IN HEIGHT AND VOLUME[1]

Study	Age	Plot shape	Avg. height *ft*	Height gain *ft/mm*	Volumn gain *cu ft/ac/mm*
Wakeley 1969	30	row	61.6	0.0	120
	30	row	54.8	2.7	970
	30	row	57.8	2.1	1,770
	30	row	55.2	1.0	-16
Clark and Phares 1961	21	block	31.8	0.4	580
	20	block	29.9	0.4	330
Dierauf 1993[2]	20	3-row	46.8	-0.07	60
Dierauf 1993[2]	19	3-row	42	0.38	130
Clark and Phares 1961	19	block	28.9	0.0	590
Sluder 1991	15	block	41	0.0	-95
Sluder 1979	15	block	48	1.2	219
	15	block	46	0.7	118
South et al. 1989	15	row	31		120
South et al. 1985	13	block	57	0.5	428
Blair and Cech 1974	13	row			279
	13	row			266
	13	row			377
	13	row			0
	13	row			-383
South et al. 1995	12	—	35	0.3	100
	12	—	35	0.3	171
Hatchell et al. 1972	10	block	29	5.4	412
	10	block	29	2.6	356
Bacon 1979	10	block	47	0.5	286
Rayonier (unpublished)	10	block	33.8	0.0	0
Silker 1960	10	row	21	0.9	112
SAFCOL (unpublished)	9	block	48.7	1.0	349
Hunt 1967	9	row	28.0	1.0	71
	9	row	29	1.0	59

[1] These values are not corrected for differences in survival.
[2] Seedbed density very high (46 to 60 plants per square foot).

A Shift in Site Index

Some people use a shift in site index to predict the gains from genetics

(Table 5). If this increase in site index is permanent, then the carrying capacity (i.e. the maximum amount of pine volume the stand can support when the current annual increment [cubic feet per acre per year] reaches zero) will be increased, and use of growth and yield models to project this increase will be appropriate.

However, the lift in site index can either be temporary or it can be permanent (Sprinz 1987). If the lift is temporary, then the maximum carrying capacity of the site will not be increased. This method is not appropriate to use when volume gains from planting morphologically improved seedlings are considered since better planting stock does not increase the maximum carrying capacity of the site. When volume gains occur due to planting seedlings with larger diameters, the gain in growth is due to a temporary lift; some call this a Type I growth response (Snowdon and Khanna 1989).

The Establishment Quality Boost

One way to model a temporary lift is to use the establishment quality boost (EQB) option in the growth and yield model PTAEDA2V. The EQB technique has been used to model gains from planting large-diameter seedlings and from herbaceous weed control. For a one-year EQB, the stand characteristics of a typical nine-year-old stand are used as the input data for the initial eight-year-old stand. Likewise, for a two-year EQB, the characteristics of a typical 10-year-old stand are used as the starting point. Yields from applying these establishment techniques are derived by increasing the stand structure.

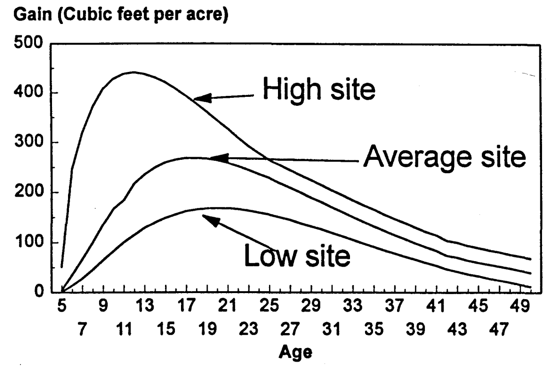
The EQB method is very different from the age-shift approach. The EQB method appears to underestimate early seedling-size gains (10 to 18 years) while overestimating gains at later ages (35 to 50 years). The EQB method also predicts a strong synergistic interaction between seedling size and herbaceous weed control (which most empirical studies do not support). South (2000) recommends that the age shift method be used instead of the EQB method.

TABLE 5. VOLUME GAINS FROM GENETICALLY IMPROVED SEEDLINGS BY INCREASING THE SITE INDEX BY 12%[1]

Age *yrs*	Site index 70 *cu ft/ac*	Site index 78.5 *cu ft/ac*	Difference *cu ft/ac*	Percent gain
15	2,319	2,915	596	25.7
25	4,437	5,647	1,210	27.3
50	5,443	6,560	1,117	20.5

[1]Using PTAEDA2V random seed number 68767 for an unthinned stand.

Figure 3. Hypothetical gains from a one-year advance in stand development for loblolly pine (South 2000).



The Age Shift Approach

A simple way to model the gains from planting morphologically improved seedlings is to advance the stand age. In other words, getting the trees off to a faster start could result in a 10-year-old stand that would have the same stand structure and would grow the same as a normal stand at age 11. This method appears more appropriate when a temporary lift in site index occurs. For loblolly pine, this method would not show much gain in per acre volume production at age 50.

A growth and yield model (Hafley et al. 1982) was used to estimate volume gains from a 1-year advance in stand development (Figure 3). This indicates that a 1-year gain will result in more volume on high sites than on low sites. On the high site, one might expect intensive management to increase productivity by about 400 cubic feet per acre per year at year 12 and by 300 cubic feet per acre at year 21. On low sites, a 1-year gain might only be 150 to 170 cubic feet per acre (at ages 15-20). Assuming the difference in RCD is 2 mm (for example, planting 6 mm seedlings vs. 4 mm seedlings), these values are similar to those reported in Table 4.

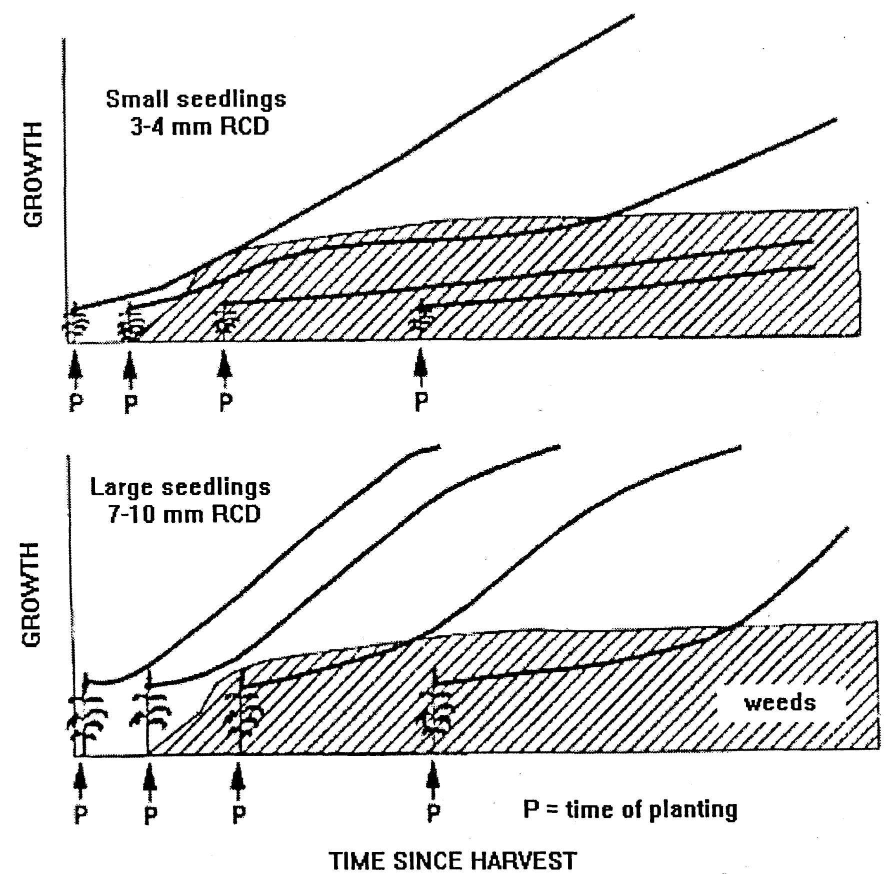
HOW TO OBTAIN A ONE YEAR AGE SHIFT

A one-year age shift can be obtained by several methods. One method would be to purchase seedlings from the local nursery and grade out all seedlings that have a RCD greater than 5 mm. The remainder could either be thrown away (very expensive) or repackaged and sold (possibly at the same price per thousand) to a contractor who likes to plant seedlings with small roots.

The results from this method should be similar to past studies where only Grade 1 seedlings were planted. However, the disadvantage of these seedlings is that since they were grown at seedbed densities near 27 plants per square foot, they would not be morphologically improved and may not have a good root-weight ratio. In some cases, there may be few seedlings with 5 or 6 mm RCD and the development of the secondary foliage may also be minimal. Any additional exposure during the grading process might negatively affect survival. Therefore, their chance of surviving a drought would be only marginally better than in the past when densities greater than 45 plants per square foot were used (Dierauf 1973).

The recommended method would be to contact a nursery manager well before sowing and have the manager contract grow seedlings at a low seedbed density (a target density of 15 to 20 plants per square foot for loblolly and slash pine). The seedlings should be cultured so that they produce many fibrous roots and should be carefully lifted to retain both a good root-weight ratio and fibrous roots. The average seedling RCD should be 6 mm (or greater). Any seedlings with RCD less than 4 mm should be culled. This method should produce growth gains similar to those in Table 4.

Figure 4. A hypothetical interaction of stock size, planting time, and weed competition on initial seedling growth (adapted with permission from Kimmins 1989).



HOW TO OBTAIN A TWO YEAR AGE SHIFT

A two-year shift in age can be achieved by planting morphologically improved seedlings and applying a herbicide application to control herbaceous weeds. In some cases, applying several applications of herbicides (during the first growing season) to regular seedlings can result in a 0.6 to 1.4 year shift in the height growth curve (Lauer et al. 1993). Although the number of published studies about the effects of applying herbicides to larger seedlings is limited, it appears that early growth gains from applying herbicides and planting morphologically improved seedlings are additive (Mitchell et al. 1988; Britt et al. 1991; South et al. 1995; South and Mitchell 1999a; South et al. 2001).

Obtaining a two-year shift in age without the use of herbicides is more difficult. The probability of actually achieving such a two-year gain is less certain because it requires a thorough understanding of interactions between planting date, seedling size, weed competition, insect pests, and soil moisture. For example, to avoid competition from herbaceous weeds, the time between harvest and planting may need to be shortened (Figure 4).

To obtain a two-year shift in age without the use of herbicides would require an integrated approach to regeneration so that no weak link spoils the efforts. To begin with, nursery cultural practices should be followed to produce an average RCD of near 8 mm without the seedlings being too tall. The seedling culling standard should be raised to at least 4 mm. In order to be economical, this will mean growing at low seedbed densities and will likely involve fall fertilization with nitrogen.

The **most important** factor would be to avoid late winter planting (late February and March). In fact, if the soil moisture is adequate, the two-year shift in age would be easier to achieve if seedlings could be planted and established in late October or early November. This would require little or no storage between lifting in the nursery and outplanting. In the past, however, planting in October was successful on an operational scale (St. Regis in Florida and Union Camp in Georgia).

Proper depth of planting would also be very important. Seedlings should be provided with a sufficiently deep hole and should be planted at least 3 inches deeper than the level at which they were grown in the nursery. Machine planting would likely be less stressful than hand- planting.

Although planting large-diameter seedlings of Douglas-fir appears to achieve an establishment boost of two or more years (Blake et al. 1989), a two-year boost with loblolly pine has not yet been documented (since studies comparing 10 mm RCD seedlings with 3 mm RCD seedlings have not been installed). However, one study with slash pine (South and Mitchell 1999a) found that early growth gains from planting 10.5 mm RCD seedlings exceeded that of applying double-bedding and a herbicide to 3.5 mm seedlings (Figure 5). Studies like this suggest that many landowners are using morphologically inferior seedlings (Table 2).

Figure 5. Effect of seedling size and intensive silviculture on early growth of slash pine seedlings (South and Mitchell 1999).

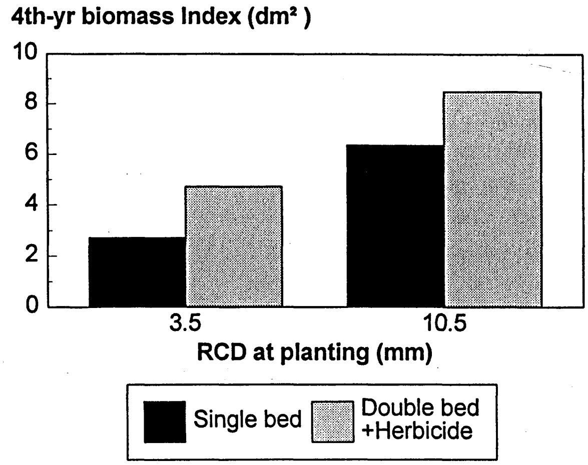
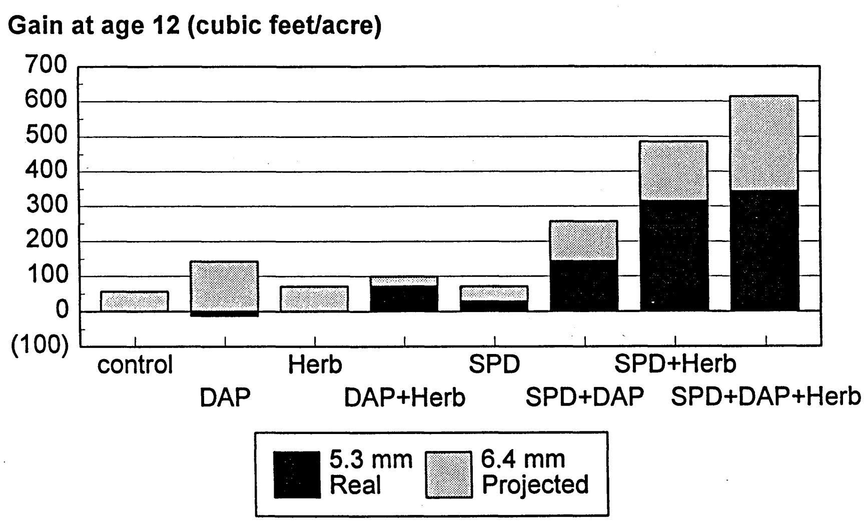


Figure 6. Realized volume gains (age 12) for various silvicultural practices using seedlings that average 5.3 mm at the groundline (black bars). Predicted volume gains due to planting slightly larger seedlings (6.4 mm) are represented by gray bars. To convert the values to an absolute basis, add 1,260 cubic feet per acre to each treatment. From this site, predicted gains from planting larger stock are greater for the more intensive treatments (South et al. 1995). DAP = diammonium phosphate; Herb = herbicide; SPD = Shear, Pile, and Disk.



PREDICTED AND REALIZED GAINS

Models can be useful for making management decisions but rarely do they predict the results for an individual site. For example, Figure 6 shows the realized gains (black bar) for planting seedlings that averaged 5.3 mm at the groundline at time of planting. The control plot included only minor site preparation (inject hardwoods with herbicide followed by a burn) while the best response was observed on an area with a shear, pile, and disk (South et al. 1995). The gray bars show the estimated volume gain from planting seedlings that averaged 6.4 mm RCD (or 1.1 mm larger at the groundline). Although the measurements were real for the 6.4 mm seedlings, the volume gains per acre were estimated (volume per acre was derived using both measured survival gains and measured individual tree volume gains).

While this could be an exaggerated estimate (South et al. 1995), it does suggest the early gains from planting large diameter seedlings are potentially greater when growth is accelerated by applying intensive silviculture. In other words, economic gains from planting morphologically improved seedlings will be greater for short-rotation, intensively managed plantations than for long-rotation, less intensively managed plantations. In one example (Figure 6), the estimated gains (due to planting larger seedlings) at age 12 for the most intensive treatment (shear + pile + disk + diammonium phosphate + the herbicide hexazinone) was 245 cubic feet per mm.

ECONOMIC ADVANTAGES OF PLANTING MORPHOLOGICALLY IMPROVED SEEDLINGS

In the past, landowners have purchased genetically improved seedlings, which cost more than seedlings that had no genetic improvement. In some cases, the difference between unimproved seedlings (called *woods run* seedlings) and genetically improved seedlings was $8 per thousand plantable seedlings. However, even when using the wrong genetic provenance, the landowner was usually willing to pay extra for genetically improved seedlings. Landowners considered the additional cost to be minimal compared to the expected additional growth.

Likewise, additional volume growth can be expected from morphologically improved seedlings but they also cost more to produce. In some cases, a nursery manager may charge $10 to $30 more for a thousand seedlings grown at low seedbed densities (15 plants per square foot) than at higher densities (27 plants per square foot).

The economic advantage of using morphologically improved seedlings will vary depending on how the plantation is managed. The economics depend on both spacing in the plantation and the timing of the first thinning. Since the use of morphologically improved seedlings does not cause a permanent lift in site index, their use for unthinned plantations on very long rotations is not recommended. In contrast, the economics can be very favorable if all the additional volume gains, due to using morphologically improved seedlings, are harvested during the first commercial thinning (age 12 to 15). The present net value of an additional 100 to 400 cubic feet of wood harvested at age 15 can easily exceed an additional $10 -$20 per acre cost in seedlings (Table 6: South et al. 1985; Caulfield et al. 1987).

The economics will also be affected by planting density. Some researchers (Bailey 1986; Borders et al. 1991) recommend outplanting up to 1,300 trees per acre (TPA) while others (Vardaman 1989; Bowling 1987) recommend outplanting 300 to 400 TPA. Therefore, the additional cost per acre for morphologically improved seedlings can vary from less than $10 (at 300 TPA) to $39 (at 1,300 TPA). Due to density-related competition, merchantable volume production at age 20 to 25 is not strictly proportional to the number of trees planted. In fact, on some sites, merchantable volume may even be the same for trees planted at 300 TPA and 1,200 TPA (Harms and Lloyd 1982; Sarigumba 1985). Therefore, the incremental gains (due to planting morphologically improved seedlings) will not be proportionally increased by planting four times as many trees. As a result, the economic advantage of using morphologically improved seedlings is much lower when outplanting densities are high. In some cases, machine planting 500 morphologically improved seedlings per acre will be less expensive than planting 726 regular seedlings (South and Mitchell 1999b).

TABLE 6. PROJECTED MERCHANTABLE VOLUME GAINS AND SUBSEQUENT GAINS IN PRESENT VALUE[1]

Year advance	Dominant height (age 15)	Harvest age	Volumn gain *cu ft/ac*	Gain/acre[2] *$*
One	60	15	400	$74
	60	20	390	$54
	50	15	260	$48
	50	20	260	$36
	40	15	150	$28
	40	20	170	$24
Two	60	15	800	$148
	60	20	770	$106
	50	15	530	$98
	50	20	510	$71
	40	15	320	$59
	40	20	330	$46

[1] Gains made by achieving a one- and two-year advance in stand development.
[2] Volume gain per acre calculated from the NCSU Plantation Management Simulator for upper-coastal plain sites. Assumes planting 360 trees per acre; a 6% real interest rate; a stumpage value of $0.60/cubic foot; and a 26% tax bracket.

SUMMARY

Loblolly and slash pine seedlings grown at low seedbed densities (less than 20 plants per square foot) are considered to be morphologically improved if they (1) are larger in diameter (half or more of the plantable seedlings have RCDs greater than 5 mm and none less than 3 mm), (2) have a higher root-weight ratio, (3) have been cultured to produce more fibrous roots, and (4) are not taller than seedlings raised at higher densities.

Survival of properly planted morphologically improved seedlings will usually be greater than seedlings grown at high seedbed densities. Although there may be no difference in survival when conditions for survival are favorable (greater than 90% survival), an increase of 4 to 10 percentage points is possible when survival of regular seedlings is less than 75%.

Machine planting is recommended when planting morphologically improved seedlings. Because they have larger roots, morphologically improved seedlings may require more time to plant properly by hand. Therefore, supervision will be essential to keep tree planters from (1) reducing the root-weight percentage by pruning and stripping roots prior to planting, (2) cramming the large roots in a shallow planting hole, or (3) failing to plant the root-collar 3 to 5 inches below the groundline.

When planted properly, morphologically improved seedlings can advance stand development by one year. A two-year advancement is possible if seedlings (averaging 8 mm RCD or more) are planted in wet soil during October or early November and herbaceous weeds are controlled with a herbicide.

The use of morphologically improved seedlings is most economical when (1) incremental gains are captured during the first commercial thinning (prior to age 20) and (2) outplanting densities are less than 500 trees per acre. It is unlikely that predicted gains from any growth and yield model will accurately reflect realized gains from a particular study or site.

REFERENCES

Autry, L.L. 1972. The residual effects of nursery fertilization and seed bed density levels on the growth of 12-, 14-, and 16-year old loblolly pine stands. M.S. Thesis, Mississippi State Univ. Starkville, 59 p.

Bacon, G.J., P.J. Hawkins, and D. Jermyn. 1977. Morphological grading studies with 1-0 slash pine seedlings. Aust. For. 40:293-303.

Bacon, G.J. 1979. Seedling morphology as an indicator of planting stock quality in conifers. Unpublished manuscript presented at Workshop on 'Techniques for evaluating planting stock quality.' New Zealand, August 1979.

Bailey, R.L. 1986. Rotation age and establishment density for planted slash and loblolly pines. South. J. Appl. For. 10:162-168.

Barnard, E.L. 1980. A comparative evaluation of seedling quality in commercial forest nurseries in Florida. p. 34-41. in Proc. 1980 Southern Nursery Conference. Lake Barkley, Kentucky.

Barnard, E.L., M.E. Kannwishcer-Mitchell, D.J. Mitchell, and S.W. Fraedrich. 1997. Development and field performance of slash and loblolly pine seedlings produced in fumigated nursery seedbeds and seedbeds amended with organic residues. pp. 86-91 in Proc. Third Meeting of IUFRO Working Party 57.03-04 Diseases and Insects in Forest Nurseries.USDA Forest Service Northern Region Forest Health Protection Report 96-7.

Barnett, J.P. and J. McGilvary. 1993. Performance of container and bareroot loblolly pine seedlings on bottomlands in South Carolina. South. J. Appl. For. 17:80-83.

Bengtson, G.W. 1963. Slash pine selected from nurserybeds: 8-year performance record. Jour. For. 61:422-425

Blair, R. and F. Cech. 1974. Morphological seedling grades compared after thirteen growing seasons. Tree Planters' Notes 25(1):5-7.

Blake, J.I. and D.B. South. 1991. Planting morphologically improved seedlings with shovels. Ala. Agric. Exp. Sta. School of Forestry Series No. 13. 7 p.

Blake, J.I., L.D. Teeter, and D.B. South. 1989. Analysis of the economic benefits from increasing uniformity in Douglas-fir nursery stock. Forestry Supplement 62:251-261.

Borders, B.E., W.D. Green, and M.L. Clutter. 1991. Variable bedding, planting, harvesting and transportation costs impact optimal economic management regimes. South. J. Appl. For. 15:38-43.

Bowling, D. 1987. Twenty-year slash pine spacing study: what to optimize? p. 300-304. in Proc. 4th Biennial Southern Silvicultural Research Conference. USDA Forest Service, General Technical Report SE-42.

Britt, J.R., R.J. Mitchell, B.R. Zutter, D.B. South, D.H. Gjerstad, and J.F. Dickson. 1991. The influence of herbaceous weed control and seedling diameter on six years of loblolly pine growth -a classical growth analysis approach. Forest Science 37:355-368.

Carlson, W.C. 1986. Root system considerations in the quality of loblolly pine seedlings. South. J. Appl. For. 10:87-92.

Carneiro, J. G. de A. 1985. Efeito da densidade sobre o desenvolvimento de alguns parametros morfofisiologicos de mudas de *Pinus taeda* L. en veneiro a apos o plantio. Unpublished thesis. Univ. of Parana, Curitiba, Brazil. 125 p.

Caulfield, J.P., D.B. South and J.N. Boyer. 1987. Nursery seedbed density is determined by short-term or long-term objectives. South. J. Appl. For. 11:9-14.

Clark, F. B. and Phares, R.E. 1961. Graded stock means greater yields for shortleaf pine. USDA Forest Service. Central States Forest Exp. Sta. Tech. Pap. 181. 5 p.

Cram, M.M., J.G. Mexal and R.A. Souter. 1997. Pisolithus tinctorius mycorrhizae inoculation provides little benefit for longleaf and loblolly pines on the Savannah River site. p. 126-133 in Proc. Third Meeting of IUFRO Working Party S7.03-04 Diseases and Insects in Forest Nurseries.USDA Forest Services Northern Region Forest Health Protection Report 96-7.

Dierauf, T.A. 1973. Loblolly pine seedling grade growth and survival. Virginia Division of Forestry Occasional Report 40. 6 p.

Dierauf, T.A., J.A. Scrivani and L.A. Chandler. 1993. Loblolly pine seedling grade - effect on survival and growth through 20 years. Virginia Department of Forestry Occasional Report 107. 38 p.

Forest Research Institute. 1988. Seedling quality and seedling specifications of radiata pine. F.R.I Rotorua, New Zealand. What's New In Forest Research No. 171. 4 p.

Greene, T.A. and S.T. Danley. 2001. Hand-lifting improves two-year field performance of loblolly pine seedlings. South. J. Appl. For. 15:38-43.

Hafley, W.L., W.D. Smith and M.A. Buford. 1982. A new yield prediction model for unthinned loblolly pine plantations. South. For. Res. Center, N.C.S.U., Raleigh, N.C., Tech. Rep. 1. 63 p.

Harms, W.R. and F.T. Lloyd. 1982. Stand structure and yield relationships in a 20-year old loblolly pine spacing study. South. J. Appl. For. 5:162-165.

Harrington, T.B. and Howell, K.D. 1998. Planting cost, survival, and growth one to three years after establishing loblolly pine seedlings with straight, deformed, or pruned taproots. New Forests 15:193-204.

Hatchell, G.E., K.W. Dorman, and O.G. Langdon. 1972. Performance of loblolly and slash pine nursery selections. Forest Science. 18:308-314.

Hitch, K.L., B.D. Shiver and B.E. Borders. 1996. Mortality models for newly regenerated loblolly pine plantations in the Georgia Piedmont. South. J. Appl. For. 20:197-202.

Hunt, D.L. 1967. Ninth-year performance of slash and loblolly pine nursery selections in Georgia. p. 92-94. in Proc. 9th Southern Conference on Forest Tree Improvement. Knoxville, Tennessee. June 8-9 1967.

Kimmins, J.P. 1989. Ecological implications of successional manipulation. p. 9-16. in Schivener, B.A. and J.A. MacKinnon (eds.). Learning from the past, Looking into the future. B.C. Ministry of Forests. FRDA report 030.

Kormanik, P.P., S.S. Sung, T.L. Kormanik and S.J. Zarnoch. 1995. Hardwood cover crops: can they enhance loblolly pine seedling production p. 86-94. in Proc. 23rd Southern Forest Tree Improvement Conference (R.J. Weir and A.V. Hatcher, comp.) Southern Forest Tree Improvement Committee Publication No. 45.

Larson, H.S. and J.N. Boyer. 1985. Root growth potential of loblolly pine (Pinus taeda L.) seedlings from twenty southern nurseries. Ala. Agric. Exp. Sta. Circular 286. 16 p.

Lauer, D.K., G.R. Glover and D.H. Gjerstad. 1993. Comparison of duration and method of herbaceous weed control on loblolly pine response through midrotation. Can. J. For. Res. 23:2116-2125.

Leach, G. N., H.H. Gresham, and Webb, A. L. 1986. Seedling grade and nursery seedling density effects on field growth in loblolly pine. Champion International Corp. Gulf States Operation Res. Note GS-86-03. 12 p.

Maclaren, J.P. 1993. Radiata pine Growers' Manual. New Zealand Forest Research Institute. FRI Bulletin 184. 140 p.

McGrath, D.A. and M.L. Duryea. 1994. Initial moisture stress, budbreak and two-year field performance of three morphological grades of slash pine seedlings. New Forests 8:335-350.

Miller, J.H., B.R. Zutter, S.M. Zedaker, M.B. Edwards and R.A. Newbold. 1995. A regional framework of early growth response for loblolly pine relative to herbaceous, woody and complete competition control: The COMProject. USDA Forest Service Gen. Tech. Rep. SO-117. 48 p.

Mitchell, R.J., B.R. Zutter, and D.B. South. 1988. Interaction between weed control and loblolly pine, Pinus taeda, seedling quality. Weed Technology 2:191-195.

North Carolina State University. 1995. Industry Cooperative Tree Improvement Program Annual Report. 20 p.

Rowan, S.J. 1986. Seedbed density affects performance of slash and loblolly pine in Georgia. p. 126-135. in Proc International Symposium on Nursery Management Practices for the Southern Pines (D.B. South, ed.). Ala. Agric. Exp. Sta., Auburn University, AL.

Rowan, S.J. 1987. Nursery seedling quality affects growth and survival in outplantings. Georgia Forestry Commission, Georgia Forest Research Paper # 70. 15 p.

Sarigumba, T.I. 1985. Sustained response of planted slash pine to spacing and site preparation. p. 79-84. in Proc. 3rd Biennial Southern Silvicultural Research Conference. USDA Forest Service Gen. Tech. Rep. SO-54.

Shipman, R. D. 1964. Low seedbed densities can improve early height growth of planted slash and loblolly pine seedlings. Jour. For. 62:814-817.

Shoulders, E. 1961. Effect of nursery bed density on loblolly and slash pine seedlings. Jour. For. 59:576-579.

Silker, T.H. 1960. Economic considerations of growing and grading southern pine nursery stock. Tree Planters' Notes 42:13-18.

Sluder, E.R. 1979. The effects of seed and seedling size on survival and growth of loblolly pine. Tree Planters' Notes 30(4):25-28.

Sluder, E.R. 1991. Seed and seedling size grading of slash pine has little effect on long-term growth of trees. Tree Planters' Notes 42(3):23-27.

Snowdon, P. and P.K. Khanna. 1989. Nature of growth responses in long-term field experiments with special reference to Pinus radiata. p. 173-186. Forest Research Institute, New Zealand, Bulletin 152.

South, D.B. 1993. Rationale for growing southern pine seedlings at low seedbed densities. New Forests 7:63-92.

South, D.B. 1998. Needle-clipping longleaf pine and top-pruning loblolly pine in bareroot nurseries. South. J. Appl. For. 22:235-240.

South, D.B. 1999. Which loblolly pine seedling has a higher survival potential – a deep planted J-root or a shallow planted I-root? P 350-355 in Proc. 10th Biennial Southern Silvicultural Research Conference. USDA Forest Service Gen. Tech. Rep. SRS-30.

South, D.B. 2000. PTAEDA2V – an establishment model for the South – should the method of modeling seedling size be changed? (In press) in Proc. First International Conference on Measurements and Quantitative Methods and Management. Jekyll Island, Georgia.

South, D.B., J.N. Boyer, and L. Bosch. 1985. Survival and growth of loblolly pine as influenced by seedling grade: 13-year results. South. J. Appl. For. 9:76-81.

South, D.B. and R.J. Mitchell. 1999a. Integration of nursery practices and vegetation management: Economic and biological potential for improving regeneration. Can. J. For. Res. 23: 2083-2092.

South, D.B. and R.J. Mitchell. 1999b. Survival of the fittest – pine seedling survival increased by machine planting large seedlings. Ala. Agri. Exp. Sta. Highlights of Agricultural Research 46(2):16-18.

South, D.B., J.G. Mexal, and J.P. van Buijtenen. 1989. The relationship between seedling diameter at planting and long term volume growth of loblolly pine seedlings in East Texas. p. 192-199 in Proc. 10th North American Forest Biology Workshop. Vancouver, British Columbia.

South, D.B., J.L. Rakestraw and G.A. Lowerts. 2001. Early gains from planting large-diameter seedlings and intensive management are additive for loblolly pine. New Forests (in press).

South, D.B. and N.J. Stumpff. 1990. Root stripping reduces root growth potential of loblolly pine seedlings. South. J. Appl. For. 14:196-199.

South, D.B., J.B. Zwolinski, and H.L. Allen. 1995. Economic returns from enhancing loblolly pine establishment on two upland sites: Effects of seedling grade, fertilization, hexazinone, and intensive soil cultivation. New Forests 10:239-256.

Sprinz, P.T. 1987. Effects of genetically improved stands on growth and yield principles. p. 228-348. in Proc. 19th Southern Forest Tree Improvement Conference, College Station, Texas.

Sung, S.S., C.C. Black, T.L. Kormanik, S.J. Zarnoch, P.P. Kormanik, and P.A. Counce. 1997. Fall nitrogen fertilization and the biology of Pinus taeda seedling development. Can. J. For. Res. 27:1406-1412.

Switzer, G.L. 1962. Some effects of nursery soil fertility on loblolly pine (Pinus taeda L.) planting stock. Ph.D. Dissertation, N.Y. State Univ., Coll. of Forestry, Syracuse Univ., Syracuse, N.Y. 181 p.

Tuttle, C.L., D.B. South, M.S. Golden and R.S. Meldahl. 1988. Initial Pinus taeda seedling height relationships with early survival and growth. Can. J. For. Res. 18:867-871.

Vardaman, J.M. 1989. How to make money growing trees. John Wiley & Sons, New York, NY. 296 p.

Venator, C.R. 1983. First-year survival of morphologically graded loblolly pine seedlings in central Louisiana. Tree Planters' Notes 34:(4) 34-36.

Wakeley, P.C. 1954. Planting the southern pines. Government Printing Office, Washington, D.C. USDA Agric. Monogr. No. 18. 233 p.

Wakeley, P.C. 1969. Results of southern pine planting experiments established in the middle twenties. Jour. For. 67:237-241.

Wilder-Ayers, J.A. and J.R. Toliver. 1987. Relationships of morphological root and shoot characteristics to the performance of outplanted bareroot and containerized seedlings of loblolly pine. p. 206-211. in Proc. 4th Biennial Southern Silvicultural Research Conference. USDA Forest Service Gen. Tech. Rep. SE-42.

Williams, H.M. and D.B. South. 1992. Effects of fall fertilizer applications on mitotic index and bud dormancy of loblolly pine seedlings. Forest Science 32:336-349.

Alabama Agricultural Experiment Station Outlying Units

Tennessee Valley Research and Extension Center (TVREC)
Sand Mountain Research and Extension Center (SMREC)
North Alabama Horticulture Research Center (NAHRC)
Upper Coastal Plain Research Center (UCPRC)
Chilton Area Research and Extension Center (CAREC)
Black Belt Research and Extension Center (BBREC)
Piedmont Research Center (PRC)
Prattville Research Field (PRF)
E.V. Smith Research Center (EVSRC)
Lower Coastal Plain Research Station (LCPRS)
Monroeville Experiment Field (MEF)
Wiregrass Research and Extension Center (WREC)
Brewton Experiment Field (BEF)
Ornamental Horticulture Station (OHS)
Gulf Coast Research and Extension Center (GCREC)
Main Agricultural Experiment Station (AAES)
at Auburn University and Alabama A&M University