INCREASING PINE SURVIVAL AND EARLY GROWTH BY PLANTING "MORPHOLOGICALLY IMPROVED" SEEDLINGS

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Abstract

"Morphologically improved" seedlings (large-diameter seedlings grown at low nursery spacings) have a higher probability of survival (about 5% better) than regular seedlings since they have larger root systems, a higher root-weight ratio (root dry weight/seedling dry weight), and have a greater root growth potential. In addition, these seedlings will grow faster during the first several years after planting. On some sites, morphologically improved seedlings will be larger in diameter at time of planting than "regular" seedlings that planted a year earlier. Morphologically improved seedlings are not available at many nurseries but they are produced at several industrial, and privately owned nurseries. The potential economic gains from planting morphologically improved seedlings increases as planting density and harvest age decreases. When planted at 333 trees per acre, these seedlings may cost $6 to $15 more per acre but may return $24 to $74/acre (present value). Well-balanced seedlings that average 6-mm at the root collar may provide a one-year advance in stand development in comparison to seedlings that average 4 mm or less. At age 15, a one-year "boost" in stand development can provide 150 cubic feet (low site) to 400 cubic feet (high site) more wood per acre.

Results from a number of studies indicate there is a substantial opportunity for increasing regeneration costs by substituting competitive seedlings rather than applying a high level of mechanical site preparation with marginal seedlings. Reducing the total amount invested in regeneration while maintaining acceptable survival and growth is a realistic goal for non-industrial landowners with limited funds.

INTRODUCTION

Loblolly pine seedlings used by most researchers and landowners are typically grown at seedbed densities greater than 25/square foot. These seedlings are typically classified as Grade 2 seedlings (see Table 1 for definitions). As a result, the seedlings used often average less than 4 mm in diameter at the root collar. Since these seedlings have small roots, survival under less than ideal conditions can be a problem. As a result, both landowners and researchers typically overplant to ensure adequate survival. Researchers sometimes double-plant (planting two seedlings per spot) in order to ensure one seedling lives. However, when researchers use large-diameter seedlings grown at low seedbed densities, they will likely observe higher rates of survival. For example, against recommendation to carefully plant only one Grade 1 seedling per spot, a study at Bainbridge, Georgia was double-planted. Since the Grade 1 seedlings were grown at low seedbed densities, and were carefully planted, almost all seedlings lived.

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 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 a 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 seedlings	These are only grown at low seedbed densities ($\leq$ 20 per square foot) and at least half of the population has root-collar diameters greater than 5 mm and none less than 3 mm). These seedlings have a higher root weight ratio, and have been cultured to give more fibrous roots, and are 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.

In the southern United States, low seedbed densities are commonly used to increase field performance potential of longleaf pine and various hardwood species. 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. Many customers do not request morphologically improved seedlings because extension agents typically do not inform landowners of the potential benefits. However, some landowners do not want morphologically improved seedlings because they have been told that seedling morphology is not important for field performance. Some researchers say that landowners should consider spending $600/acre for intensive plantation management without saying that morphologically improved seedlings is a key feature to improving early growth. As a result, some may wonder why the early growth of their stand is not the same as that seen on land owned by Champion, Rayioner, U.S. Alliance, or Union Camp.

SEEDLING SURVIVAL

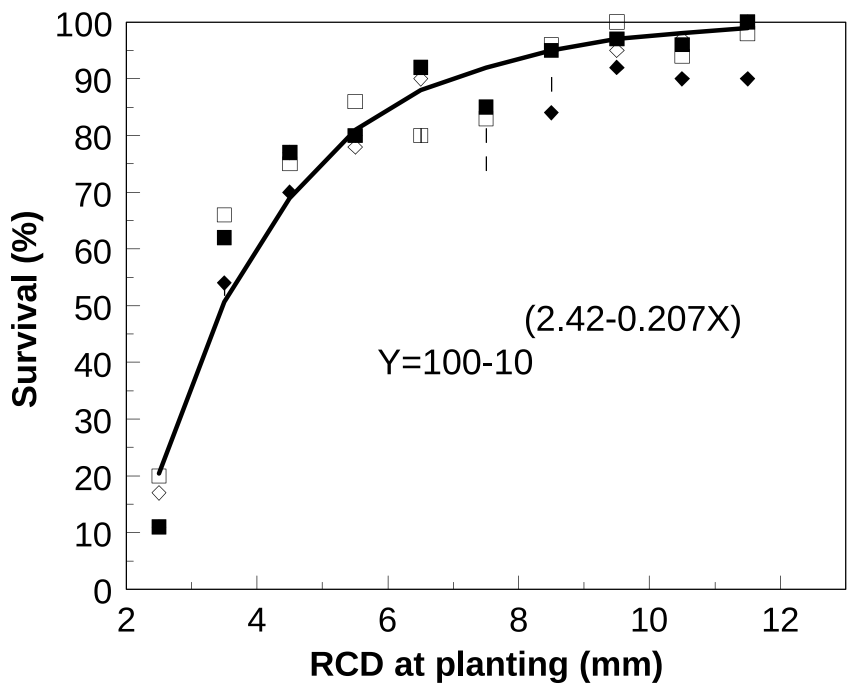

Figure 1. Relationship between seedling root-collar diameter and survival.

Figure 1 shows the relationship between root-collar diameter (RCD) at planting and seedling survival on one site in Georgia. Although not all sites will show this relationship, this does illustrate a general pattern that has observed over the past 50 years (South 1993). When properly planted, the large diameter seedlings (with higher root-weight ratios) typically survive better than the smaller seedlings.

The average RCD of loblolly pine seedlings used by most researchers in the southern United States is rather small (Table 1). However, some companies like Union Camp, Champion, U.S. Alliance, and Rayioner believe that seedling performance is related to RCD and that with proper lifting and planting, seedling with large diameters tend to survive and grow better than small diameter seedlings (McGrath and Duryea 1994; South 1993). As a result, the target seedling RCD for these companies is 6 mm (or greater). This is about 2 mm larger than seedlings used by most researchers (table 1).

"Morphological improvement" is enhancing the performance potential of forest tree planting stock through the application of nursery management practices (primarily growing at low seedbed densities). Although the vocabulary may sound new, the practice of growing pine seedlings at low seedbed densities has been used to improve the performance potential of pine seedlings throughout the world. For example, since the early 1970's, 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 easy sites (with low elevation), densities of 15 seedlings per square foot are used.

However, lower densities (12 seedlings per square foot) are recommended for more adverse, high-elevation sites (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).

Table 1. The groundline diameter (GLD) or root-collar diameter (RCD) of “regular” bare-root loblolly pine seedlings typically used in research studies.

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

INCORRECT INFORMATION

Many people have been told that seedling morphology is a poor indicator of seedling performance. While it is certainly true that seedling morphology is not a PERFECT predictor of field SURVIVAL, it is wrong to say that seedling morphology is a poor indicator of GROWTH potential. In fact, seedling morphology is about the best tool we have to separate individual seedlings prior to planting according to their potential for GROWTH. Although knowing the genotype usually does not help predict field SURVIVAL, this does not mean we should not use genetically improved seedlings in order to improve the GROWTH potential of a stand. As with genetically improved seedlings, the main reason we should be using morphologically improved seedlings is to improve the GROWTH potential of our plantations.

Some of those who say that seedling morphology is a poor predictor of survival cite old studies conducted in the 1930's when seedbed densities were high. Others cite more recent studies that used seedlings from seedbeds with densities greater than 45 per square foot (Dierauf 1993). Some studies confound seedling morphology with other factors that affect survival. Although several studies show positive correlations between root-collar diameter and survival (Dierauf 1993; South 1993; McGrath and Duryea 1994), these studies are not cited by those who claim that seedling morphology is a poor predictor of field survival.

FACTORS THAT INFLUENCE SEEDLING SURVIVAL

Initial survival in the field is affected by several factors. The most important factor is the outplanting environment (i.e. soil water content at time of planting, hard freeze soon after planting, extended drought just after planting, soil texture, soil depth, weed competition, insect pests). Seedling handling is also very important. The timing of lifting, the type of lifting machine, the amount of cold storage, the temperature of cold storage, root stripping during lifting, root pruning after lifting, **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). The next important factor is seedling morphology (i.e. root weight ratio, root mass, root collar diameter, secondary foliage, and seedling height. Seedling physiology is also important and can be influenced by the nursery environment (excessive rain, lack of soil oxygen, freezes, high temperatures, photoperiod, pathogens, cultural practices, toxic chemicals) as well as handling practices (i.e. time of lifting, amount of cold storage, root desiccation, etc.). However, seedling physiology can be very difficult to evaluate on individual seedlings at time of outplanting.

To a limited extent, the genetics of a seedling will affect initial survival (through its affect 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 Coop Annual Report). Even so, genetics (especially on a species level and provenance level) usually has a greater impact on the potential longevity of a stand than on initial stand establishment. The following model lists in order of relative importance, some of the partially controllable factors that affect initial outplanting survival.

SURVIVAL=ENVIRONMENT+ HANDLING + morphology + physiology

“MORPHOLOGICALLY IMPROVED” SEEDLINGS SURVIVE BETTER

Seedlings grown at low seedbed densities will usually survive better due to having more strong first order lateral roots, more short roots, more foliage, and a better root weight ratio (morphologically improved). Contrary to popular belief, seedlings produced from low seedbed densities are usually taller. In the past, it has been the very tall seedlings grown at high seedbed densities (and as a result, low root weight ratios) and planted out on areas with limited moisture that survived poorly when outplanted. For example, when grown at the same seedbed density, slash pine seedlings that are 7 inches tall may exhibit much better survival (66% survival) than seedlings that are 13 inches tall (35% survival) (Bengtson 1963). When growing under high seedbed densities, it is likely that the shorter seedlings will survival better than taller seedlings (Sluder 1991; Dierauf 1993).

Several studies demonstrate better survival from seedlings grown at wide seedbed spacings (Table 2). When average survival was greater than 96%, seedbed density will have little or no effect on survival. However, when the average survival is less than 90%, "morphologically 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 per square foot.

Table 2. Increase in seedling survival by using loblolly pine seedlings that were grown in the nursery at low seedbed densities.

Study	Low Density	Medium Density	Survival Gain
	----- #/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

Root Weight Ratio

Although low seedbed densities will result in seedlings with better root weight ratios, it is very important that the root weight ratio is not 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. Less injury has been observed on seedlings when lifting by hand (Barnard 1980) or when using a Fobro-type lifter to assist hand lifting.

Although a number of studies demonstrate the balance between roots and shoots is important to seedling survival, some researchers have implied that a morphological trait (such as a 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 that 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). However, 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 none of the studies where Grade 2 seedlings survived better than Grade 1 seedlings was it demonstrated that the root weight ratio was not correlated with survival.

Root Growth Potential

One reason why more roots improve seedling survival is due to the ability of seedlings to quickly produce new roots soon after planting. This ability is related to a seedling's "root growth potential" which a measure of the new root growth under controlled conditions. Theoretically, seedlings that can produce many new roots within a few weeks of planting will survive better than seedlings that produce only a few new roots. Some researchers believe that seedling morphology has little to do with the ability of a seedling to quickly produce new roots. However, research at Auburn University and Weyerhaeuser has demonstrated a positive correlation between root biomass and root growth potential. Apparently, the more fibrous lateral roots a seedling has, the more sites are available for new root growth. Seedlings that produce more new roots have a greater ability to take up more water (Carlson 1986).

A WORD OF CAUTION

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. This may explain in part why some operational foresters have observed that "Grade 1 seedlings do not survive as well as Grade 2 seedlings." The survival benefits of growing seedlings at low seedbed densities will be destroyed if removing roots reduces the root-weight-ratio. The root growth potential of seedlings can be reduced in half by the single act of stripping the roots through a closed fist. Therefore, the results from research studies can differ greatly from that of operational studies if unsupervised tree planters strip and prune roots prior to planting.

In addition, seedlings with large root systems that are not planted deep enough (due to making too small of a planting hole) will also not survive well. 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 grown at high seedbed densities (that have less roots, less foliage, and lower root weight ratios).

SEEDLING GROWTH

Although survival benefits can result from proper planting of "morphologically improved" seedlings, the greatest and most consistent benefit is from an increase in growth. It is clear Table 3 that increases in per acre volume gains can be made at ages 10 to 15 by planting seedlings with large diameters (especially if they have good root weight ratios). In most cases, the gains will result from both better survival and better average tree growth. In no case did Grade 1 seedlings grow less (on an individual tree basis) than the Grade 2 seedlings (lower per acre production could only be attributable to poorer survival; likely a result of poorer root weight ratios; or taller seedlings; or inexperience in planting larger stock).

Table 3. Effect of seedling size on gains in height and volume

Study	Age	Plot shape	Avg. ht	Height gain	Volume gain
			--feet--	feet/mm	cu.ft/acre/mm
Wakeley 1969	30	row	61.6	0.0	120
	30	row	54.8	2.7	970
	30	row	57.8	2.1	1770
	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 *	20	3-row	46.8	-0.07	60
Dierauf 1993 *	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
Hunt 1967	9	row	28	1.0	71
	9	row	29	1.0	59

These values are not corrected for differences in survival.
* seedbed density very high (46-60/square foot)

PREDICTING PER ACRE VOLUME GAINS

It is not enough to just 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 some estimate of how much volume gains can be expected. Estimates of volume gain per mm increase in seedling diameter have been calculated for the above examples. For example, if we assume the average root-collar diameter for a Grade 2 seedling is 4 mm, and we assume that the average for a Grade 1 seedling is 6 mm, then we can divide the volume difference by 2 to get an estimate of the volume gain per mm. If we exclude the 30-year row-plot data, the average gain in volume amounts to about 190 cubic feet/mm. This suggests that, on average, stands that are 15 to 20 years old will have an extra 380 cubic feet/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 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 "% gain" varies with age. The "% gain" in per acre volume observed at age 8 will not be the same as that for unthinned plantations at age 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!

A SHIFT IN SITE INDEX

Some use a shift in site index to predict the gains from genetics. If this "lift" 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/acre/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. When considering volume gains from planting "morphologically improved" seedlings, we do not use this method since better planting stock does not increase in maximum carrying capacity of the site. We believe that 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).

Table 4. Predicted volume gain from increasing site index by 12% using Ptaeda2V and random seed number 68767 for an unthinned stand.

Age (years)	Site index 70 (cu.ft/acre)	Site index 78.5 (cu.ft/acre)	Difference (cu.ft/acre)	% gain
15	2319	2915	596	25.7
25	4437	5647	1210	27.3
50	5443	6560	1117	20.5

A SHIFT IN AGE

One way to model a temporary “lift” is to advance the stand age. In otherwords, 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 (from NCSU) was used to estimate the volume gain from a 1-year advance in stand development (the NCSU model outputs average values while Ptaeda2V requires the user to average the results from 10 or more different runs). Figure 2 suggests that when using intensive management to pine productivity to about 300 cubic feet/acre/year (high site), one might expect an additional 400 cubic feet/acre (at ages 10-19) from planting morphologically improved seedlings (as opposed to regular stock). On low sites, this gain might only be 150 to 170 cubic feet/acre (at ages 15-20). Assuming the difference in RCD 2 mm (e.g. 6 mm seedlings vs. 4 mm seedlings), these values are similar to those reported in Table 3.

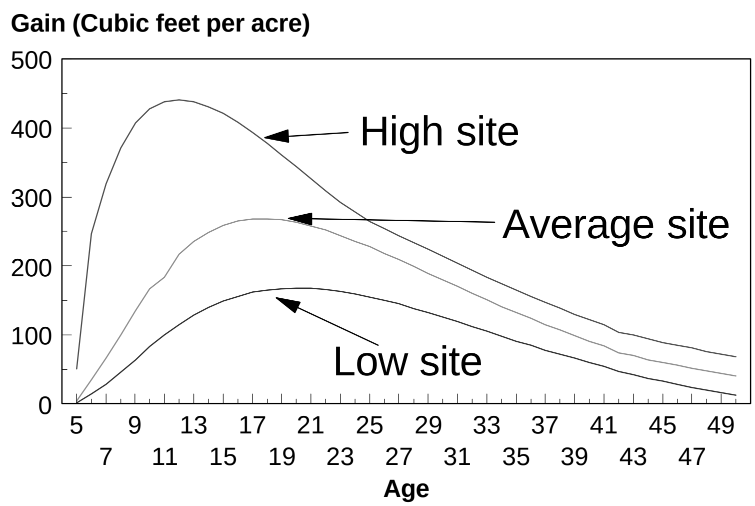

Figure 2. Hypothetical gains from a 1-year advance in stand development for loblolly pine.

HOW TO OBTAIN A ONE YEAR AGE SHIFT

Obtaining a 1-year age shift should be in one of two methods. One method would be to purchase seedlings from the local nursery, grade out all seedling that have a root collar diameter greater than 5 mm. You could either throw the remainder away (very expensive) or repackage them and sell them (possibly at the same price per thousand) to a contractor that 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/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. Therefore, their chance of surviving a drought would be only marginally better than in the past when densities greater than 45/square foot were used (Dierauf 1993).

The recommended method would be to contact a nursery manager well before sowing and have the manager contract grow seedlings at low a seedbed density (a target density of 15 to 20/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 root-collar diameters less than 4 mm should be culled. This method should produce growth gains similar to those in Table 3.

HOW TO OBTAIN A TWO YEAR AGE SHIFT

Obtaining a 2-year shift in age can be achieved by planting morphologically improved seedlings and applying a herbicide application to control herbaceous weeds. In several 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 amount of published studies combining herbicides with larger seedlings is limited mostly to large seedlings grown at typical seedbed densities, the early results appear to indicate the early growth gains from adding herbicides to morphologically improved seedlings are additive (Mitchel et al. 1988; Britt et al. 1991; South et al. 1995).

Obtaining a 2-year shift in age without using herbicide will be more difficult. Although it can be done, the probability of actually achieving such a gain is less certain because it takes a sound understanding of regeneration practices to consistently obtain such a gain. An integrated approach to regeneration would be required so that no "weak link" spoils the efforts. First, the nursery cultural practices should be followed to produce an average root-collar diameter of near 8 mm without 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. **MOST IMPORTANT** is to avoid late winter planting (late February and March). In fact, if the soil moisture is adequate, the two-year shift in age will be easier to achieve if the seedlings can be planted and established in late October or early November. This would require little or no storage between lifting in the nursery and outplanting. However, it has been very successful on an operational scale (St. Regis in Florida and Union Camp in Georgia). Proper depth of planting is most important. Seedlings should be provided with a sufficiently deep hole and should be planted at least 2 inches deeper than the level at which they were grown in the nursery. Although planting large-diameter seedlings of Douglas-fir appears to achieve an establishment “boost” of 2- or more years (Blake et al. 1989), a 2-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 suggests that early growth gains from planting 10.5 mm RCD seedling can exceed that of applying double-bedding and a herbicide to 3.5 mm seedlings (Figure 3). Studies like this suggest that many studies use morphologically inferior seedlings (Table 1).

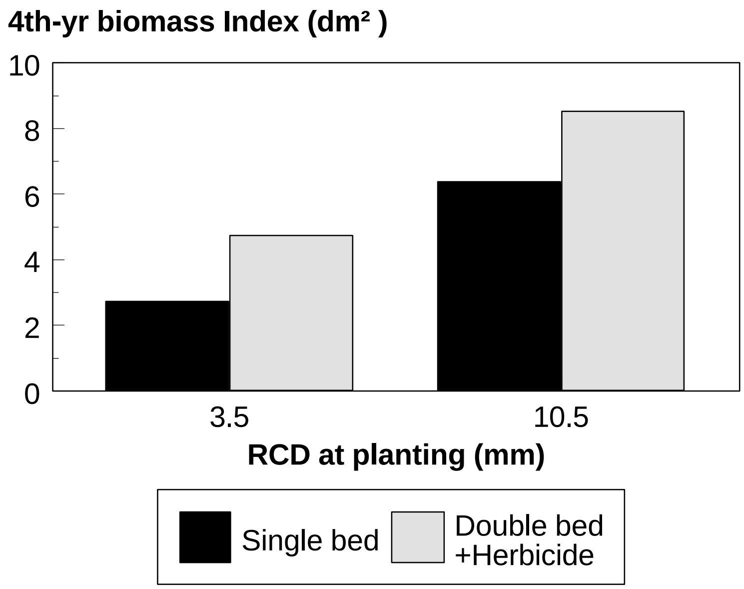

Figure 3. Effect of seedling size and intensive silviculture on early growth of slash pine seedlings.

PREDICED 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 4 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 white 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). Although this could be an exaggerated estimate (see 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, the gains from planting morphologically improved seedlings will likely be greater for short-rotation, intensively managed plantations than on sites of low productivity and long rotations. In this example, the estimated gains (due to planting larger seedlings) at age 12 for the most intensive treatment (shear + pile + disk + DAP + hexazinone) was 245 cubic feet/mm.

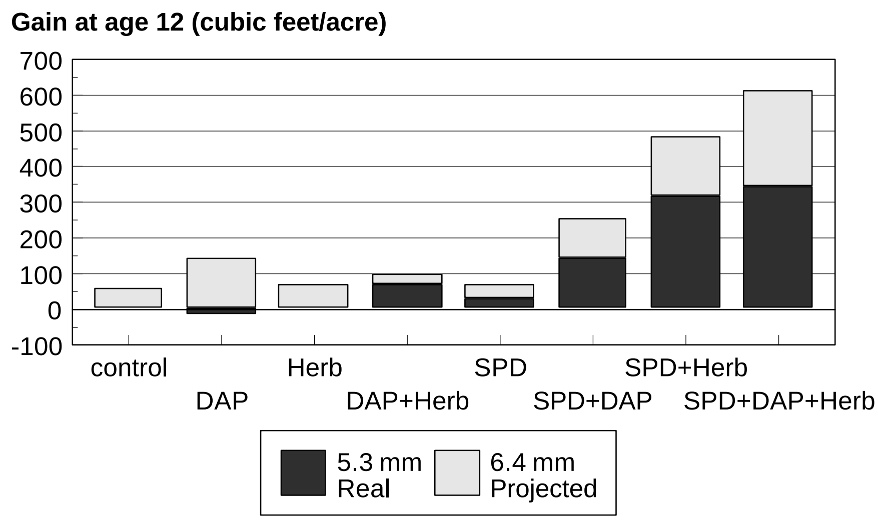

Figure 4: Realized volume gains (age 12) for various silvicultural practices using seedlings that average 5.3 mm at the groundline (black bars). Predicted volume gains due to planting slightly larger seedlings (6.4 mm) are represented by gray bars. From this site, predicted gains from planting larger stock are greater for the more intensive treatments (South et al. 1995).

ECONOMICS

In the past, landowners have purchased genetically improved seedlings which cost more than "regular" seedlings. In some cases, the difference between "woods run" and "genetically improved" seedlings was $8 per thousand plantable seedlings. However, even when using the wrong provenance, the landowner was usually willing to pay extra for "genetically improved" seedlings. This resulted because the additional per acre cost was minimal in comparison 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/ft^2) than at higher densities (27/ft^2).

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 (Table 5) harvested at age 15 can easily exceeds an additional $10 -$20 per acre cost in seedlings (South et al. 1985; Caulfield et al. 1987).

The economics will also be affected by planting density. Some (Bailey 1986; Borders et al. 1990) recommend outplanting up to 1300 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 1300 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 1200 TPA (Harms and Lloyd 1982; Sarigumba 1985). Therefore, the incremental gains (due to planting "morphologically improved" seedlings) will not be proportionally increased by planting 4 times as many trees. As a result, the economic advantage of using "morphologically improved" seedlings is much lower when outplanting densities are high.

Table 5. Projected merchantable volume gains by achieving a one-and two-year advance in stand development and subsequent gains in present value from achieving such gains.

Year Advance	Dominant Height (age 15)	Harvest Age	Volume gain (cu.ft./acre)	$ gain/acre
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	80	$148
	60	20	770	$106
	50	15	530	$98
	50	20	510	$71
	40	15	320	$59
	40	20	330	$46

Volume gain/acre calculated from the NCSU Plantation Management Simulator for upper-coastal plain sites. Assuming planting 360 trees per acre; a 6% real interest rate; a stumpage value of $60/cunit; and a 26% tax bracket.

SUMMARY

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

2: 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 (>90% survival), an increase of 4 to 10 percentage points increase is very possible when survival of "regular" seedlings is less than 75%.

3: Although relatively easy to machine plant, "morphologically improved" seedlings may require more time to plant properly by hand. Therefore, supervision will be essential to prevent 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; (3) failing to plant the roots 2 to 3 inches deeper than the level grown in the nursery.

4: When planted properly, "morphologically improved" seedlings can result in an advancement of 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 if herbaceous weeds are controlled with a herbicide.

5: The use of "morphologically improved" seedlings are 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.

6: It is unlikely predicted gains from any growth and yield model will accurately reflect realized gains from a particular study or site.

LITERATURE

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. Pp. 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 S7.03-04 Diseases and Insects in Forest Nurseries.USDA Forest Services 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., 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., Green, D.W., and M.L. Clutter. 1990. Variable bedding, planting, harvesting and transportation costs impact optimal economic management regimes. South. J. Appl. For. 14:(in press).

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 e 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. Pp. 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.

Feret, P.P. and R.E. Kreh. 1985. Seedling root growth potential as an indicator of loblolly pine field performance. For. Sci. 31:1005-1011.

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.

Harms, W.R. and F.T. Lloyd. 1982. Stand structure an 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. For. Sci. 18:308-314.

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

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.

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., Gresham, H. H. 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. Nore GS-86-03. 12 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.

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.

Meekins, E.H. 1964. A case for planting graded stock. Tree Planters' Notes 66:7-8.

Nebgen, R.J. and J.F. Meyer. 1986. Seed bed density, undercutting, and lateral root pruning effects on loblolly pine seedling morphology, field survival, and growth. P. 136-147. 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. 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. S0-54.

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. Pp. 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., 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(2):76-81.

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.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 fertiilzation 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.

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

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