Table 3. Survival, diameter, height, and yield of Choctawhatchee sand pine at age 11 years planted on Georgia sandhills in strips made with different site preparation equipment.

Site preparation[a]	Rows/strip	Survival (%)	Diameter (in.)	Height (ft)	Volume[b] (ft^3/ac)
V-blade	1	82	4.1	23.4	495
KG-blade	2	88	4.1	23.7	530
KG-blade	3	87	3.9	23.5	465
Chop & disk	2	90	4.2	24.7	575

[a] There were no significant differences between site preparations for survival, growth, or yield.
[b] Stem volume outside bark to a 1-in. top.

growth rate of trees on strips at age 11 years appears to be the same as for trees on sites receiving complete site preparation. In addition, the leave strips preserve a source of mast and other wildlife foods while the strip configuration creates an edge, providing more potential for wildlife production.

Strip site preparation is not suited to every landowner, but it is a viable alternative for some. A similar approach, on selected sites, may be appropriate for other species of southern pine. □

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Foliar Nitrogen Content at Lifting Correlates with Early Growth of Loblolly Pine Seedlings from 20 Nurseries[1]

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ABSTRACT. Height growth of outplanted loblolly pine seedlings was monitored over a 3-year period. Growth of seedlings from 20 nurseries was correlated with initial seedling characteristics from paired samples. Height growth during the first 6 months after planting was negatively correlated with the initial seedling height and shoot/root ratio and was positively correlated with root growth potential (RGP) and root weight. However, these variables were not significantly correlated with later growth. Foliar nitrogen content (mg of foliar nitrogen per seedling) was positively correlated with both initial and subsequent field growth. Foliar nitrogen content was the only variable that was significantly correlated with diameter growth and volume growth during the third year after planting. This variable accounted for 36% of the variation among sample means for 3-year height growth. These data support a previous report that field performance of loblolly pine seedlings during the first 3 years in the field can be influenced by the foliar nitrogen content at lifting.

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Several studies have described the growth of outplanted pine seedlings produced from different nurseries (Nelson and Switzer 1966, Burns and Brendemuehl 1971, Blair and Cech 1974, Donald 1986, Rose 1986). In one study, volume production of seedlings (ranging in diameter from 3.2 to 4.7 mm) from two nurseries differed by more than 7 m^3/ha/yr (1 cunit/ac/yr) (Blair and Cech 1974). If this degree of variation in volume production can be attributed to nursery cultural practices, then it will be beneficial to identify those nursery factors that affect volume production.

The total volume production is a function of both growth and survival. Thus, attempts should be directed toward identifying seedling characteristics that are important for seedling survival versus those which are important for seedling growth. Previous attempts have been made to identify factors responsible for growth differences among seedlings from different nurseries. Some studies were for only one year (Omi et al. 1986, Rose 1986, Feret et al. 1986), while others reported growth over a three-, four-, or five-year period (Donald 1986, Nelson and Switzer 1966, Burns and Brendemuehl 1971).

In 1982, this study was established in Alabama to determine

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which seedling characteristics may be important for seedling survival and early growth. Analysis of third-year data has identified characteristics that are potentially important for early growth. Results on seedling survival have been reported elsewhere (Larsen et al. 1986).

MATERIALS AND METHODS

Samples of loblolly pine (*Pinus taeda* L.) seedlings were obtained from 20 southern forest nurseries from December 7 to December 17, 1982 (Larsen and Boyer 1986). Nurseries were located in 6 southern states below latitude 33°30′N. Mother trees varied among the samples, but all mother trees were located in Livingston Parish, Louisiana. The main purpose of this study was not to compare stock performance of individual nurseries, but rather to encompass a range of possible seedling conditions.

At each nursery, all seedlings in a 60-cm strip of bed were carefully hand-lifted, some for use in a greenhouse study of RGP, the rest for use in an outplanting study. The seedlings were placed on ice in an insulated cooler and transferred to a common cold storage until planting. An adjacent sample from the same bed was lifted and 15 seedlings from this sample were selected for mineral analysis of foliage, stems, and roots. Those seedlings were oven-dried at 70°C and ground to pass through a 20-mesh screen before analysis. Techniques used for analysis have been described previously (Boyer and South 1985). The concentration (percent or ppm) and content (mg per seedling) in the foliage, stems, and roots were determined for N, P, K, Mg, Ca, S, Na, Mn, Fe, Al, B, Cu, and Zn.

Seedlings from the first sample were graded by root collar diameter and culls were removed. From each of these 20 nursery samples, 20 seedlings with root collar diameters between 3 and 5 mm were selected for greenhouse testing of RGP and bud activity. When possible, seedlings over 25 cm in height were excluded (no greenhouse sample contained more than 4 seedlings over 25 cm in height). Seedlings with southern fusiform rust (*Cronartium quercuum* (Berk.) Miyabe ex Shirai f. sp. *fusiforme* Burdsall and Snow) or with severe stem or root deformities were not used.

On December 20, white root tips were removed and the seedlings were potted with coarse sand in 2-l wax-coated cartons with drainage holes. The potted seedlings were kept on a rooting bed in a greenhouse under a 16-hour photoperiod for 28 days. Methodology and conditions of the test have been described previously (Larsen and Boyer 1986). Although all of the seedlings ceased terminal growth before potting, many resumed growth in the greenhouse. Because this occurred, the seedlings' terminal buds were inspected after 23 days in the greenhouse. A bud was classified as active if it had swollen to the extent of revealing some of the green needle tips or was elongating. The following measurements were also obtained for each seedling: number and lengths of new roots (≥0.5 cm and ≥1.5 cm in length) and dry weights of new roots, original roots, stem, and foliage.

The outplanting study was established on December 21 and 22. From each nursery sample, 108 seedlings were selected for outplanting. One of the outplanted samples contained 30% culls, one contained 47% culls, and one contained all culls. For the remaining samples, the outplanted seedlings consisted of only Grade 1 and Grade 2 seedlings (Wakeley 1954).

The planting site was a gently sloping, well-drained, upland old-field site at the E. V. Smith Research Center in Macon County, Alabama. Existing vegetation consisted of a scattering of upland hardwood seedlings and saplings with a mixture of grasses and forbs and some patches of woody vines. All vegetation was mowed prior to planting. In March 1984, all hardwood sprouts that grew during 1983 were sheared near ground level and treated with a herbicide to limit resprouting.

The soil series for about half of the planting site area is Cuthbert, but small areas of Shubuta, Blanton, Guin, and overlying colluvium are also present. The predominant topsoil texture on the site is light sandy loam, ranging from 0 cm to over 75 cm in depth and averaging about 25 cm. Gravel content of the topsoil averages about 10%. The subsoil texture is predominantly silty clay.

Trees were planted using a randomized block experimental design, with 9 trees per plot and 12 replications (except for one nursery that had 9 replications) Seedling heights were recorded on February 19, June 30, and November 13, 1983, while heights and groundline diameters were recorded on November 19, 1984, and November 27, 1985. Stem volumes at age 2 and 3 were calculated as the volume of a cone.

Plot means for the various growth measurements were subjected to analysis of variance using SAS's GLM procedure (SAS Institute 1982). The model tested was that for a randomized complete block design with both treatments (nurseries) and blocks treated as fixed effects (Snedecor and Cochran 1974). Correlations between growth and various seedling characteristics were calculated to help identify areas for future research. Variables tested included morphological characteristics of seedlings from the greenhouse test, the RGP and bud activity status of seedlings from the greenhouse test, and mineral concentrations and contents for the paired seedling samples. For the sake of brevity, correlations with root and stem mineral analyses are not reported here. All correlations represent 20 nursery means.

RESULTS AND DISCUSSION

Average growth of seedlings during the first three years in the field is shown in Table 1. After 3 years, seedlings from the fastest

Table 1. **Average growth of loblolly pine seedlings during three years after planting at the E. V. Smith Research Center in Macon County, AL.**

Nursery of origin[1]	Foliar nitrogen content	Initial seedling height	Initial height growth, Feb.–June 1983	Subsequent height growth increments July–Nov. 1983	1984	1985	Total height growth	Root-collar diameter growth, 1985	Volume growth, 1985
	(mg)	(cm)						(mm)	(cm^3)
1	19.9	13	18	8	52	101	179	20	632
2	21.4	18	15	7	48	104	174	23	768
3	26.2	14	11	8	46	101	166	21	621
4	14.8	6	14	8	46	98	166	19	492
5	18.8	11	13	7	50	106	176	22	686
6	15.1	19	12	8	52	111	182	23	861
7	18.4	21	12	6	47	99	164	21	727
8	23.8	13	16	10	55	112	193	24	958
9	10.5	18	10	6	43	100	160	20	556
10	8.7	18	7	6	38	88	139	19	502
11	17.3	19	11	8	50	103	173	23	754
12	17.4	19	7	7	41	99	155	20	494
13	15.3	19	14	8	57	114	193	24	924
14	17.0	13	15	7	46	100	170	21	661
15	18.6	17	12	7	45	93	158	19	589
16	10.3	22	6	6	42	91	145	20	575
17	14.5	15	13	6	41	95	156	20	665
18	9.3	20	13	7	47	109	176	22	753
19	23.8	18	8	6	41	94	150	20	541
20	18.4	24	9	7	48	100	164	22	791
Mean	17.0	16.8	11.6	7.1	46.8	100.8	166.9	21.0	677.2
C.V.[2]	28.6	11.0	23.1	47.0	24.9	18.4	19.1	19.0	47.7
M.S.E.[3]	—	3.5	7.2	11.1	136.2	344.1	1012.2	16.0	104444
Error d.f.	—	206	204	201	200	200	200	200	200
$P > F$[4]	—	0.0001	0.0001	0.1164	0.0043	0.0454	0.0012	0.0293	0.0045

[1] Nursery codes are the same as those reported by Larsen and Boyer (1986).
[2] C.V. = Coefficient of variation
[3] M.S.E. = Mean square error
[4] $P > F$ = Probability of a greater F-statistic in test of nursery effect

growing sample had twice the volume and were 36% (56 cm) taller than seedlings from the slowest growing sample.

Initial Shoot Growth (through June 30, 1983)

There was a negative relationship between average seedling height at planting and initial shoot growth (Table 2). Thus, taller seedlings initially grew less than shorter seedlings. A negative relationship between seedling height and initial height growth has been reported for other sites in Alabama where survival was below 75% (Tuttle et al. 1987). Average first-year survival in this study was 65%.

Initial height growth was also correlated with original root weight, shoot/root ratio, and RGP (Table 2). Although these variables can be important for both growth and survival during the seedling establishment phase (Carlson 1986, Larsen et al. 1986), they were not significantly correlated with subsequent growth in this study. Apparently, RGP and seedling morphology determined the degree of expression of growth potential during the first six months by influencing seedling water balance.

Except for nitrogen, no foliar minerals were significantly correlated with early shoot growth. Although both foliar nitrogen content and foliar nitrogen concentration were positively correlated with growth, they were not correlated with seedling survival (Table 2). These data support previous conclusions (Switzer and Nelson 1963, Nelson and Switzer 1966, Landis 1985) that nutrient status is more closely related to growth after planting than to survival.

Data in Table 2 demonstrate the limitation of using only the first year's height growth data to identify seedling characteristics that are important for continued growth. If only first-year shoot growth had been reported, conclusions about the relative importance of foliar nitrogen content might have been different from the conclusions reached in this three-year study.

Subsequent Growth

Foliar nitrogen content accounted for more than 25% of the variation in height growth for all three years in the field. This was the only variable that was significantly correlated to both diameter and volume growth during 1985. Foliar nitrogen concentration, foliar phosphorus concentration, and foliar phosphorus content were also correlated with total height growth. However, for our data, phosphorus concentration and content, respectively, were correlated with nitrogen concentration (R = 0.79) and content (R = 0.98). It should be mentioned

Table 2. **Correlation coefficients of various measures of seedling RGP, morphology, and mineral nutrition with survival and periodic average seedling growth increment at the E. V. Smith Research Center in Macon County, AL (N = 20).**

Seedling Parameter	Survival, Nov. 1983	Initial height growth, Feb.–June 1983	Subsequent height growth increment July–Nov. 1983	1984	1985	Total height growth	Diameter growth, 1985	Volume growth, 1985
Stem length	−0.52*[1]	−0.63**	−0.40	−0.33	−0.17	−0.37	0.08	0.07
Original root weight	0.64**	0.59**	0.34	0.30	0.25	0.37	0.23	0.14
First-year survival	—	0.56**	0.36	0.43	0.32	0.44	0.18	0.18
Shoot/root ratio	−0.76***	−0.55*	−0.33	−0.29	−0.15	−0.31	−0.09	−0.04
Number of new roots ≥0.5 cm	0.85***	0.52*	0.29	0.36	0.26	0.37	0.09	0.04
Weight of new roots ≥0.5 cm	0.81***	0.52*	0.35	0.32	0.26	0.36	0.12	0.04
Total seedling weight	0.34	0.39	0.26	0.27	0.31	0.34	0.31	0.23
Foliage weight	0.22	0.38	0.38	0.35	0.39	0.41	0.33	0.27
Bud activity	0.60**	0.37	0.32	0.30	0.06	0.23	−0.01	0.07
Foliar N content	0.30	0.56**	0.53*	0.54*	0.53*	0.60**	0.45*	0.46*
Foliar N (%)	0.23	0.46*	0.40	0.48*	0.39	0.48*	0.34	0.43
Foliar P content	0.32	0.44	0.43	0.43	0.50*	0.51*	0.42	0.37
Foliar P (%)	0.32	0.41	0.38	0.46*	0.50*	0.51*	0.40	0.40

[1] * = significant at 0.05 level; ** = significant at 0.01 level; *** = significant at 0.001 level.

that at lifting, the foliar phosphorus concentrations (mean = 0.21%) were generally higher than the optimum range (0.14 to 0.16%) reported by Fowells and Krauss (1959). However, the nitrogen concentration (mean = 1.7%) was at the low end of the optimum range of 1.7% to 2.3% as suggested by Fowells and Krauss (1959).

Switzer and Nelson (1963) also found that third-year height of loblolly pine seedlings was related to foliar nitrogen content. Both their study and our study suggest that seedling growth by age 3 can be correlated with foliar nitrogen content (Figure 1). Higher R^2 values for Switzer and Nelson's data may be because their data represents a wider range of means from only one nursery.

Switzer and Nelson (1963) cautioned against employing nitrogen concentration as the sole criterion of seedling quality. In some years, nitrogen fertilization in pine seedbeds can significantly improve seedling weights, but the additional fertilization may not change the foliar nitrogen concentration (Switzer and Nelson 1963, van den Driessche 1984). A dilution of foliar nitrogen can even occur when larger seedlings are produced (Schomaker 1969, McClain and Armson 1976, Barnett 1984). For example, Burns and Brendemuehl (1971) reported that cull (Grade 3) seedlings had slightly higher nutrient concentrations than heavier Grade 1 or Grade 2 seedlings. However, after five growing seasons, the height growth for the Grade 1 seedlings was about 40% more than for the cull seedlings. The correlation between foliar nitrogen concentration and early growth might be improved by comparing seedlings of equal size and foliage weight.

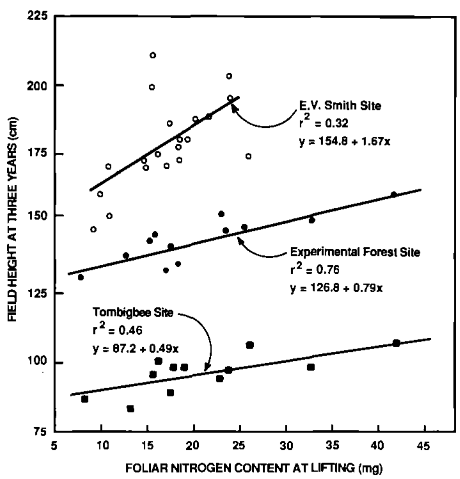

Figure 1. The relationship between third-year field height and foliar nitrogen content (mg/seedling) at lifting for the E. V. Smith Research Center site in Macon County, AL, the Experimental Forest site in Oktibbeha County, MS, and the Tombigbee site in Lowndes County, MS. (Solid symbols from 1957 outplantings by Switzer and Nelson 1963.)

Although seedling mineral content is often more closely correlated with growth than with mineral concentration (Landis 1985), the mineral content is confounded with seedling size. For example, the simple correlation between foliage dry weight and foliar nitrogen content for our data was 0.77. The data reported by Switzer (1962) also confounds nitrogen content with initial seedling size. For third-year heights, he obtained good correlations with both seedling dry weight (R = 0.89) and foliar nitrogen content (R = 0.92). However, seedling size can also be confounded with mineral concentration of seedlings from fertilizer studies. For example, both Switzer (1962) and van den Driessche (1980) reported significant relationships between seedling size and foliar nitrogen concentration. Therefore, for these and other studies (van den Driessche 1982, van den Driessche 1984) it is not clear whether the growth response attributed to fertilization is a result of planting a larger seedling with more roots and foliage, or is a result of planting a seedling with better nitrogen status, or both.

Our findings differ from the findings of others in that there was no strong correlation between growth and total seedling weight (or foliage weight). Also, the foliar nitrogen concentration was not correlated ($R < 0.08$) with either foliage dry weight or total seedling dry weight. This suggests the confounding of seedling size with nutrient concentration is less of a problem for our data and, therefore, the observed growth differences between seedling samples were largely due to physiological differences induced by different nursery environmental conditions and cultural regimes. For example, fertilization records from the 20 nurseries indicate that the median amount of nitrogen applied in 1982 was 91 kg/ha (81 lb/ac) and the total amount ranged from 24 kg/ha (21 lb/ac) to 297 kg/ha (265 lb/ac).

To help separate the growth response due to foliar nitrogen level from that due to seedling size, a multiple regression model was employed as suggested by Landis (1985). The model Y (3-year height growth) = 102.6 + 27.9 (foliage weight in g) + 0.00215 (foliar nitrogen concentration in ppm) produced an R^2 of 0.38. For this model, nitrogen concentration accounted for about 60% of the model sum of squares. Evaluating the relative contribution of seedling size and foliar nitrogen level is important, since both variables have been correlated with average tree volumes after 16 years (Autry 1972).

The above correlations and questions demonstrate that research is needed in the area of seedling nutrition for the southern pines. Current recommendations for the "optimum" levels of foliar nitrogen for loblolly pine are not based on studies reporting growth after outplanting. In the southern United States, there has been almost no research in this area since the work conducted by Switzer and Nelson (1963). This could result from an apparently stronger concern for improving seedling survival than for improving seedling growth with better nursery management practices. □

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