Long-Term Effects of Drainage, Bedding, and Fertilization on Growth of Loblolly Pine (*Pinus taeda* L.) in the Coastal Plain of Virginia

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ABSTRACT: *A site preparation study was established in 1968 at three locations in the Coastal Plain of Virginia. Three treatments were installed in a randomized complete block design: (1) chop, (2) bed, and (3) ditch. In 1978, four fertilizer treatments were superimposed on the site preparation study: (1) check, (2) phosphorus (P) only, (3) P + nitrogen (N), and (4) P + N + lime, converting it into a split-plot design. At age 33 years, height of the dominant loblolly pine in the ditch treatment was significantly greater than in the other site preparation treatments. However, there were no differences in stand density, diameter at breast height (dbh), basal area, or volume because of site preparation. This contrasts with the data collected at age 21 years, when total volume in both the bed treatment and the ditch treatment was greater than in the chop treatment. Changes in water table depths through time were the probable cause for decreased response to bedding and ditching. There was a large response to fertilization through age 33 years in this study. The P + N + lime treatment had significantly greater dbh, basal area, and volume than the other fertilizer treatments, which significantly increased pine stumpage value. The size of the growth response was greater at age 33 years than it was at age 21 years. Soil and foliage analysis suggests that the sustained growth response at this site was due to the added Ca. South. J. Appl. For. 29(4):205–214.*

Key Words: Site preparation, nitrogen, phosphorus, lime, calcium.

Intensive site preparation and fertilization often are required to successfully establish and ensure rapid growth of loblolly pine (*Pinus taeda* L.) in the South (Lowery and Gjerstad 1991, Jokela et al. 1991, Fox et al. 2004). Consequently, site preparation and fertilization are widespread silvicultural practices in plantations throughout the region. More than 1 million ac were site prepared in 2002 (Dubois et al. 2003) and almost 1.2 million ac were fertilized in 2001 (North Carolina State Forest Nutrition Cooperative [NCSFNC] 2002).

Site preparation practices such as drainage and bedding that manage excess water and improve soil aeration significantly improve the survival and early growth of planted seedlings on poorly drained soils in the Coastal Plain (Terry and Hughes 1975, Terry and Hughes 1978, Gent et al. 1986, Lowery and Gjerstad 1991, Schultz 1997). However, the long-term effect of these site preparation treatments on growth and yield of rotation age loblolly pine is not well documented. Few well-designed and replicated studies have followed the response through an entire rotation.

Wilhite and Jones (1981) reported on an unreplicated case study involving bedding and drainage in slash pine (*Pinus elliottii* Engleman.) stands on poorly drained, sandy soils in northern Florida. Using stem analysis, they found that the growth advantages associated with bedding and drainage were greatest at age 17 years and then declined

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through time. Trees on bedded plots were still 5.7 ft taller than those on unbedded plots at age 35 years. Tiarks and Haywood (1996) used a replicated experiment to compare no tillage, flat disking, and bedding at two sites with poorly drained silty-clay soils in southern Louisiana. They found that bedding improved tree growth through 15 years at one site and 20 years at the second site. Because of recent declines in pulpwood stumpage prices (Harris et al. 2004), sawtimber management regimes with rotation lengths of 25–35 years are favored by many landowners. Therefore, it would be helpful to have additional information on the growth response to site preparation practices such as drainage and bedding during longer rotations.

Nutrient deficiencies, particularly phosphorus (P), severely limit tree growth on many poorly drained soils in the Coastal Plain (Wells et al. 1973). Large growth responses after P fertilization have been observed on these soils (Pritchett et al. 1961, Gent et al. 1986, Jokela et al. 1991). The growth response to P fertilization on these soils often continues through the entire rotation (Pritchett and Comerford 1982, Harding and Jokela 1994) and may last into a second rotation (Ballard 1978, Gentle et al. 1986, Comerford et al. 2002). Loblolly pines on most sites in the South respond well to nitrogen (N) fertilization in combination with P (Allen 1987, Jokela et al. 1991, Fox et al. 2004). However, little information exists on the growth response of loblolly pine to other nutrients such as Ca. Although liming is a common practice for production of agricultural crops on the acid soils of the South (Adams 1984, Brady and Weil 2002), it is generally considered that loblolly pine is naturally adapted to infertile, acid, low cation exchange capacity soils, where Ca availability is low and therefore will not respond to liming (Lyle and Adams 1971). However, Ca deficiencies have been observed in loblolly pine, particularly in seedlings (Davis 1959, Sucoff 1961, and Lyle 1969). The growth response of loblolly pine planted in the field to liming has been inconstant in the few cases where it has been studied. McCarthy and Davey (1976) reported a significant growth increase because of Ca over 6 years in loblolly pine growing on an organic soil in a Pocosin in eastern North Carolina. Van Lear (1980) also observed a positive growth response in loblolly pine through 5 years when lime and N were added in a midrotation stand in the South Carolina Piedmont. In contrast, Moschler et al. (1970) found no effect of liming on growth of loblolly pine in the Virginia Piedmont. A negative growth response was reported after liming on a Spodosol from the South Carolina Coastal Plain (Coultas et al. 1991).

The objective of the present study was to document the long-term growth response, through the age of 33 years, of loblolly pine to site preparation and fertilization on poorly drained mineral soils in the Coastal Plain of Virginia.

Materials and Methods

Study Site Description

The original study was designed to evaluate the effect of harvesting and site preparation on water table levels and growth of planted loblolly pine seedlings. The study was initiated in 1968 at three locations in the Coastal Plain of Virginia near the towns of Whaleyville (36°34.1′ N; 76°38.9′ W), Holland (36°40.1′ N; 76°41.7′ W) and Windsor (36°51.1′ N; 76°44.0′ W). Average annual rainfall in the area is 48 in., with 30 in. falling between Apr. and Sept. Average temperature in Jan. is 39° F and in July is 77° F.

The three sites were characterized as wet pine flats. The landscape was nearly level with a slope of less than 2%. Soils were infertile and strongly acidic with a sandy surface overlying an argillic horizon that extended from 10 in. to approximately 80 in. The soils at all three sites were dominated by poorly drained Myatt (fine-loamy, siliceous, active, thermic Typic Endoaquults) and Rains series (fine-loamy, siliceous, semiactive, thermic Typic Paleaquults), but included small areas of the somewhat poorly drained Lynchburg series (fine-loamy, siliceous, semiactive, thermic Aeric Paleaquults). The study areas were dissected by an irregular road network that provided some primary drainage because the elevated roadbeds were constructed using spoil from roadside ditches on one or both sides of the roads.

Loblolly pine with a minimum age of 45 years comprised a minimum of 50% of the overstory basal area at each site when the study was initiated. Site index at a base age of 50 years at all three sites was approximately 70 ft. The overstory also contained a mixture of pond pine (*Pinus serotina* Michaux.), red maple (*Acer rubrum* L.), blackgum (*Nyssa sylvatica* Marsh.), sweetbay (*Magnolia virginiana* L.), and water oak (*Quercus nigra* L). The understory vegetation included a mixture of switch cane (*Arundinaria gigantea* (Walter) Muhl.), sweet pepperbush (*Clethra alnifolia* L.), and greenbrier (*Smilax* spp.).

Site Preparation Experiment

The study was designed as a randomized complete block with four treatments at each location with each of the three locations serving as blocks. Each treatment comprised 10 ac, so total area at each location was approximately 40 ac. One-acre measurement plots were located in each treatment area and the plot corners were surveyed before harvest. A 10-ac portion of each site was left as an uncut control. During the spring and summer of 1968, the remaining 30 ac at each location were clearcut, with all stems greater than 4 in. at groundline cut and merchantable material removed. The timber at each site was harvested so that site disturbance during logging was minimized. Timber was hand felled and removed from the location of the measurement plots with a crane equipped with a grapple. In this manner, logging equipment did not impact the measurement plots.

Then, the site preparation treatments were imposed on three 10-ac portions of the harvested stand during the late summer and fall of 1968. One of the blocks, located near Windsor, Virginia, was too wet to be site prepared at that time. Site preparation was completed at this site in the summer of 1970. The three site preparation treatments were

Chop. A roller drum chopper was used to crush slash and residual stems, and then the site was burned.

Bed. The site was windrowed, burned, and bedded. The windrows were 10–15 ft wide and contained large amounts of slash, forest floor, and topsoil. Measurement plots were located between the windrows, with at least 50 ft from the plot edge to the windrow.

Ditch. Ditches approximately 6 ft deep were dug before harvest through the treatment area. The ditches were dug from the access roadside ditch into the stand, and in the center of the treatment area a 1-ac square was completely enclosed by the ditch, except for a small "bridge" of unditched area that provided access to the interior. The measurement plot was located inside the area enclosed by the ditch. After harvest, the slash was roller drum chopped and burned.

Loblolly pine seedlings were planted at a 10 × 6-ft spacing during Feb. and Mar. of 1969, except for the site near Windsor, which was planted during Apr. 1971. Total height of the planted loblolly pine was measured at ages 1, 2, 3, and 5 years on 25 randomly selected pines in each plot.

Six water table wells were installed at random locations in each measurement plot before harvest. Depth of the water table was recorded biweekly before harvest from Aug. 1967 to Apr. 1968. The location of the water table wells was then surveyed and they were removed and steel plates were placed over the holes 1 ft below the ground surface to permit harvesting and site preparation treatments to be installed. The water table wells were reinstalled after harvesting and site preparation was completed. Next, depths of the water table were measured biweekly during the 1st, 2nd, and 3rd year after planting.

The drainage study was discontinued in 1976. The early data from the site preparation study were previously summarized by Young (1972) and Langdon (1976).

Fertilization Experiment

A fertilization experiment was superimposed on the original study in 1978, converting it into a split-plot design with the original site preparation treatments serving as the main plot factors and the fertilizer treatments serving as the split-plot factors. Before the initiation of this phase of the study, the uncut control stands of the original site preparation study were harvested. Thus, only three site preparation treatments remained: chop, bed, and ditch. Each of the 1-ac measurement plots from the original site preparation study were split into four 0.25-ac subplots and the following fertilizer treatments were applied in Apr. 1978:

Check. No fertilization.

P. Seventy-five pounds per acre of elemental P applied as triple superphosphate.

P + N. Seventy-five pounds per acre of elemental P applied as triple superphosphate + 100 lb/ac of elemental N applied as urea.

P + N + lime. Seventy-five pounds per acre of elemental P applied as triple superphosphate + 100 lb/ac of elemental N applied as urea + 2,000 lb/ac of Dolomitic lime, which supplied approximately 540 lb/ac of elemental Ca and 158 lb/ac of elemental Mg.

A 0.033-ac circular plot was established in the center of each of the 0.25-ac fertilizer treatment plots. Hardwoods on the plots with basal diameters greater than 0.5 in. were cut using hand tools and left in place in Apr. 1978. Heights and dbh of the loblolly pine were measured at the time of fertilization and after each of the following two growing seasons.

Soil and foliage samples were collected in 1981 at which time the study was again discontinued. No conclusions were made concerning the effect of the fertilizer treatments at that time and, unfortunately, the data from that period were lost.

Data Collection

In 1991, the study plots were relocated to determine the continuing effect of the site preparation and fertilization treatments on loblolly pine growth and site hydrology. Heights and dbh of the loblolly pines in the 0.033-ac circular plots were measured. The original water table wells also were relocated and the water table depths were monitored biweekly for 14 months from Apr. 1991 to May 1992. The data on the growth response of loblolly pine from this period were summarized by Andrews (1993). Data on species diversity and overall ecosystem productivity from this period were reported by Hauser et al. (1993).

The plots were relocated and measured in 2003 to determine the long-term effect of site preparation and fertilization on growth of loblolly pine. Height and dbh of all loblolly pine in the 0.033-ac circular plots were measured. Dominant height was determined using the height of the tallest 10 trees in each plot, which was used to calculate site index based on the equations of Amateis and Burkhart (1985). Total tree volume was determined using the equation developed by Cao and Burkhart (1980). Net standing per acre pine volume in each treatment plot was then calculated. It was not possible to calculate gross pine volume production because we could not account for volume lost due to mortality between measurement periods. Height and dbh of all hardwoods taller than 4.5 ft in the measurement plots were measured also. Stumpage value of the timber produced in the various treatments was computed using southwide averages from Timber Mart-South for the fourth quarter of 2004: \$6.66/ton for pine pulpwood ($\leq$7.5 dbh), \$23.24/ton for pine chip-n-saw ($7.5 > \text{dbh} \leq 11.5$), \$39.54/ton for pine sawtimber ($>$11.5 dbh), and \$5.83/ton for hardwood pulp (Timber Mart-South, www.tmart-South.com/tmart/ Apr. 29, 2004).

Soil and foliage samples were collected in 2003 to determine the long-term effect of site preparation and fertilization on site fertility. Composite samples of the surface 6 in. of the mineral soil, comprised of 10 subsamples collected with a push tube, were taken in each 0.033-ac circular plot. The soils were air-dried and then ground. Soil pH was determined using a combination glass electrode (Thomas 1996). Total C and N in the soil were determined by dry combustion on a CN analyzer (Elementar Analysesysteme GmbH, Hanau, Germany) (Nelson and Sommers 1996).

Mechlich 3 extractable P, K, Ca, and Mg were determined by inductively coupled plasma spectrophotometry (Kuo 1996). Foliage samples were collected by shooting a branch from the upper third of the crown of five dominant or codominant loblolly pines on each 0.033-ac circular plots in Dec. 2003. Ten intact fascicles from the first flush of the previous growing season were collected from each tree and composited into a sample of 100 fascicles per plot. Foliage was dried to a constant weight at 150° F, weighed, and ground to pass a 16-mesh screen. N was analyzed by dry combustion on a CN analyzer and P, K, Mg, and Ca were determined by inductively coupled plasma spectrophotometry after a nitric acid digest (Kou 1996, Nelson and Sommers 1996).

Statistical Analysis

The data were analyzed as a spilt-plot design with three blocks using analysis of variance (Gomez and Gomez 1984). Site preparation treatments were the main plot factors and fertilizer treatments were the subplot factors. The three locations served as blocks. Mean separations were conducted using Duncan's Multiple Range Test at a significance level of 0.10. When significant interactions between site preparation treatments and fertilizer treatments were detected for a response variable, separate analyses of variance and mean separation were conducted for the subplot factors at each level of the main plot factor to explain the interaction (Freund and Little 1981). All statistical analyses were conducted using SAS (SAS Institute, Cary, NC).

When the study was measured in 2003, the planted loblolly pines were 33 years old in two of the blocks and 31 years old in one of the blocks. Because the younger block had been sold by the original landowner and was scheduled for harvest, it was not possible to delay the final measurement to achieve a common age. However, because the age of loblolly pine was the same within each block, valid statistical comparisons were possible by analyzing the data as a split-plot design with three blocks. To determine if the different stand ages in the individual blocks would affect the results, data from the individual plots in the 31-year-old block were input into the FASTLOB loblolly pine growth-and-yield model (Virginia Polytechnic Institute and State University, Blacksburg, VA) and grown for 2 years. Values for stand density, dbh, average height, dominant height, basal area, and volume for this block were adjusted to the age of 33 years in this manner. Data from all three blocks at this common age were then used to repeat the statistical analysis. Although this approach resulted in slight differences in block and treatment means compared with the unadjusted data, the results of the statistical analyses were the same using the original data and the data adjusted to a common age. This confirmed that because the trees within the individual blocks were the same age, the age differences were adequately accounted for in the block effect in the analysis of the unadjusted data. Therefore, the original unadjusted data will be presented in this article and will be referred to as age 33 years for convenience.

Results

Site Preparation and Fertilization Interactions

The only significant interaction between site preparation treatments and fertilization treatments was found for average tree height of the loblolly pine ($P = 0.0433$). Average tree height was significantly less in the bed treatment compared with the chop and ditch treatments in the unfertilized plots (Figure 1). There were no significant differences in average height of the loblolly pine because of site preparation in the other fertilization treatments. There were no significant treatment interactions for stand density, dominant height, dbh, basal area, stand volume, soil, and foliage nutrient concentrations. Therefore, the main effects of site preparation and fertilization will be presented separately for these variables.

Site Preparation Effects on Tree Growth

At age 33 years, site preparation still significantly affected height of the dominant loblolly pine (Table 1). Dominant trees in the ditch treatment were taller than trees in the bed treatment (78.8 ft versus 70.5 ft, respectively). However, there were no significant effects of site preparation on stand density, mean dbh, or basal area at age 33 years (Table 1). Stand density averaged 281 trees/ac, ranging only from 276 to 288 trees/ac. Mean tree dbh ranged from 9.0 in. in the bed treatment to 9.6 in. in the chop treatment. Basal area was 133 ft^2/ac in the bed treatment, 146 ft^2/ac in the ditch treatment, and 154 ft^2/ac in the chop treatment. There were no significant differences in stand volume among the site preparation treatments at age 33 years, which ranged from 3,886 ft^3/ac in the bed treatment to 4,846 ft^3/ac in the chop treatment (Table 1; Figure 2A). Consequently, site preparation had no effect on stumpage value (Table 1). Site preparation also had no effects on density, height, dbh, or basal area of the hardwoods at age 33 years (Table 2). The hardwoods were predominantly in the lower crown classes as evidenced by their shorter height, which averaged 46.8 ft, and smaller dbh, which averaged 4.7 in. dbh in all the site preparation treatments.

Fertilization Effects on Tree Growth

A significant effect of fertilizer and lime applied at age 9 years on the growth of loblolly pine was still evident at age

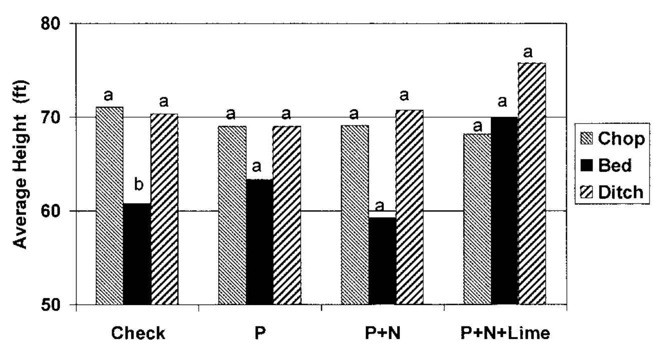

Figure 1. Interaction between site preparation and fertilization at age 9 on the average height of loblolly pine in the Coastal Plain of Virginia at age 33. Bars within a fertilization treatment with the same letter are not significantly different ($\alpha = 0.10$).

Table 1. Effect of site preparation and fertilization on stand density, height of dominant trees, dbh, basal area, total stand volume, and stumpage value of loblolly pine at age 33 yr in the Coastal Plain of Virginia.

	Stand density (trees/ac)	Height of dominants (ft)	dbh (in.)	Basal area (ft^2/ac)	Total volume (ft^3/ac)	Stumpage value ($/ac)
Site preparation treatment	$P = 0.483$	$P = 0.071$	$P = 0.590$	$P = 0.455$	$P = 0.351$	$P = 0.298$
Chop	288a	76.1ab	9.6a	154a	4846a	3721a
Bed	276a	70.5 a	9.0a	133a	3880a	2868a
Ditch	278a	78.8 b	9.5a	146a	4749a	3594a
Fertilization treatment	$P = 0.558$	$P = 0.056$	$P = 0.082$	$P = 0.038$	$P = 0.010$	$P = 0.002$
Check	268a	74.4 a	9.3a	136a	4184a	3967a
P	284a	74.2 a	9.2a	141a	4323a	4045a
P + N	282a	73.7 a	9.1a	137a	4172a	3960a
P + N + lime	287a	78.3 b	9.9b	164b	5286b	4896b

P values are for split-plot analysis of main plot factor (site preparation) and subplot factor (fertilization). Values within a column for site preparation main effect or fertilization main effect followed by the same letter are not significantly different ($\alpha = 0.1$).

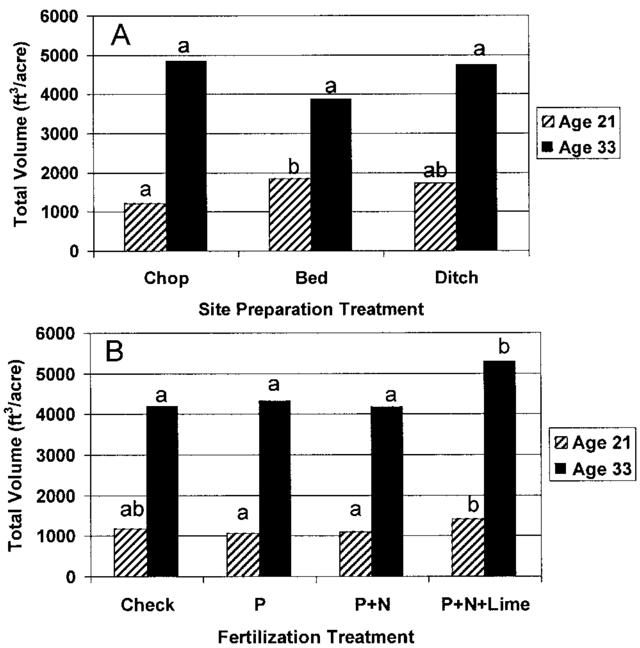

Figure 2. Effects of A) site preparation, and B) fertilization at age 9, on total volume of loblolly pine in the Coastal Plain of Virginia at age 21 and age 33. Bars at the same measurement age with the same letter are not significantly different (α=0.10).

33 years (Table 1). Liming in combination with P and N fertilization significantly increased height of dominant trees, dbh, basal area, and volume compared with the other fertilizer treatments and the unfertilized check. Height of the dominant trees was 4 ft greater in the P + N + lime treatment, which averaged 78 ft, as compared with P only and P + N fertilizer treatments, and the check, all which averaged approximately 74 ft. Basal area was 164 ft^2/ac in the P + N + lime treatment compared with 136–141 ft^2/ac in the check, P, or P + N treatments, a 16–21% increase. The dbh in the P + N + lime treatment was 0.6–0.8 in. greater compared with the other treatments. In the P + N + lime treatment, 95% of the pine stems were classed as chip-n-saw or sawtimber with a dbh greater than 7.5 in. and in the check, P, and P + N treatment approximately 90% of the stems were large enough to meet chip-n-saw or sawtimber specifications. Stand volume ranged from 4,172 to 4,323 ft^3/ac in the check, P, and P + N fertilizer treatments compared with 5,286 ft^3/ac in the P + N + lime treatment (Table 1; Figure 2B). This represents an increase of 22–27% in stand volume because of fertilization with P + N + lime compared with the fertilization with P or P + N or the unfertilized check treatment. A similar trend was evident in stand volume in the fertilized treatments when measured at age 21 years (Figure 2B). Fertilization had no effect on the hardwoods in the overstory and the midstory (Table 2). As a result of these differences in pine stand volume and product class distribution, there was a significant difference in timber value among the fertilizer treatments at age 33 years (Table 1). Stumpage value in the P + N + lime treatment was $4,896/ac, which was significantly higher than in the other three fertilizer treatments where stumpage value ranged from $3,960 to $4,045/ac.

Site Preparation and Fertilization Effects on Soil Properties

Site preparation had no effect on pH, total C, total N, or extractable P, K, Ca, or Mg in the surface soil (Table 3). However, fertilization at age 9 years still had an effect on chemical properties of the surface soil at age 33 years (Table 3). Soil pH was still slightly higher in the P + N + lime treatment. Extractable P concentrations also were generally higher in the P, P + N, and P + N + lime treatments as compared with the unfertilized check. Extractable P increased from approximately 16 ppm in the check to 23 and 25 ppm in the P and P + N treatments, respectively. Extractable Ca and Mg were significantly higher in the P + N + lime treatment compared with the other treatments (Table 3). Extractable Ca was 58 ppm in the P + N + lime treatment and only 18–24 ppm in the other treatments. Likwise, extractable Mg was 23 ppm in the P + N + lime treatment compared with 10–13 ppm in the other treatments. Soil C, N, and K were not affected by the fertilizer treatments.

Site Preparation and Fertilization Effects on Nutrient Concentrations in Foliage

Site preparation had little effect on nutrient concentrations in the foliage of loblolly pine at age 33 years (Table 4). There were no significant differences in N, P, Ca, or Mg concentrations in the foliage because of site preparation. Potassium concentrations in the foliage were significantly higher in the ditch treatment (0.432%) than in the other two

Table 2. Effect of site preparation and fertilization on trees per acre, total height, dbh, and basal area of hardwoods at age 33 yr in the Coastal Plain of Virginia.

	Density (trees/ac)	Mean height (ft)	dbh (in.)	Basal area (ft^2/ac)
Site preparation treatment	$P = 0.696$	$P = 0.422$	$P = 0.962$	$P = 0.820$
Chop	124a	48.4a	4.7a	16a
Bed	145a	47.3a	4.7a	19a
Ditch	127a	44.8a	4.6a	15a
Fertilization treatment	$P = 0.815$	$P = 0.927$	$P = 0.731$	$P = 0.817$
Check	133a	47.3a	4.7a	17a
P	123a	46.7a	4.8a	16a
P + N	141a	47.0a	4.7a	18a
P + N + lime	130a	46.1a	4.5a	15a

P values are for split-plot analysis of main plot factor (site preparation) and subplot factor (fertilization). Values within a column for site preparation main effect or fertilization main effect followed by the same letter are not significantly different ($\alpha = 0.1$).

Table 3. Effect of site preparation and fertilization on chemical properties of the surface 6 in. of mineral soil at age 33 yr in loblolly pine plantations in the Coastal Plain of Virginia.

				Mehlich 3 extractable			
	pH	Total C (%)	Total N (%)	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)
Site preparation treatment	$P = 0.835$	$P = 0.530$	$P = 0.456$	$P = 0.288$	$P = 0.829$	$P = 0.309$	$P = 0.417$
Chop	4.30a	4.67a	0.17a	20.5 a	43.9a	24.6a	14.1a
Bed	4.32a	4.09a	0.15a	16.3 a	37.1a	18.6a	11.4a
Ditch	4.31a	3.55a	0.11a	25.4 a	40.1a	49.6a	18.5a
Fertilization treatment	$P = 0.071$	$P = 0.246$	$P = 0.232$	$P = 0.019$	$P = 0.673$	$P = 0.031$	$P = 0.032$
Check	4.32a	3.57a	0.12a	15.9 a	50.5a	17.7a	10.1a
P	4.29a	4.21a	0.15a	23.5bc	38.3a	23.3a	12.9a
P + N	4.31a	4.31a	0.14a	25.0 c	32.6a	24.5a	13.0a
P + N + lime	4.40b	4.34a	0.15a	18.5ab	40.0a	58.3b	22.8b

P values are for split-plot analysis of main plot factor (site preparation) and subplot factor (fertilization). Values within a column for site preparation main effect or fertilization main effect followed by the same letter are not significantly different ($\alpha = 0.1$).

Table 4. Effect of site preparation and fertilization on foliar nutrient concentration in loblolly pine at age 33 yr in the Coastal Plain of Virginia.

	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
Site preparation treatment	$P = 0.927$	$P = 0.545$	$P = 0.074$	$P = 0.432$	$P = 0.365$
Chop	1.268a	0.098 a	0.339a	0.154 a	0.066a
Bed	1.257a	0.089 a	0.318a	0.101 a	0.057a
Ditch	1.277a	0.111 a	0.432b	0.153 a	0.070a
Fertilization treatment	$P = 0.881$	$P = 0.067$	$P = 0.490$	$P = 0.097$	$P = 0.566$
Check	1.266a	0.086 a	0.386a	0.120 a	0.063a
P	1.263a	0.102ab	0.327a	0.115 a	0.061a
P + N	1.283a	0.115 b	0.391a	0.141ab	0.068a
P + N + lime	1.260a	0.093 a	0.349a	0.169 b	0.067a

P values are for split-plot analysis of main plot factor (site preparation) and subplot factor (fertilization). Values within a column for site preparation main effect or fertilization main effect followed by the same letter are not significantly different ($\alpha = 0.1$).

site preparation treatments, which were 0.318 and 0.339%, respectively, in the bed treatment and the chop treatment.

Fertilization at age 9 years significantly increased P and Ca concentrations in the foliage at age 33 years (Table 4). Foliar P concentrations were 0.115% in the P + N treatment, which was higher than the check treatment that averaged 0.086 ppm. Foliar Ca concentrations were significantly higher in the P + N + lime treatment, which averaged 0.169%, compared with the other treatments, which averaged from 0.120% in the check treatment to 0.141% in the P + N treatment. There were no significant differences in foliar N, K, or Mg concentrations at age 33 years caused by fertilization at age 9 year.

Site Preparation and Fertilization Effects on Soil Water Tables

After harvest, water tables rose (Figure 3A). During the period from Jan. to Dec. 1969, water tables were at or near the surface of the soil for significant periods of time in the chop treatment and the bed treatment (Langdon 1976). In contrast, water tables were consistently between 50 and 100 cm below the soil surface in the ditch treatment during this period (Figure 3A). Water table data collected during 1991 and 1992 revealed that water tables were well below the soil surface in all three site preparation treatments throughout this period (Figure 3B). There were no effects of fertilization on water table depths.

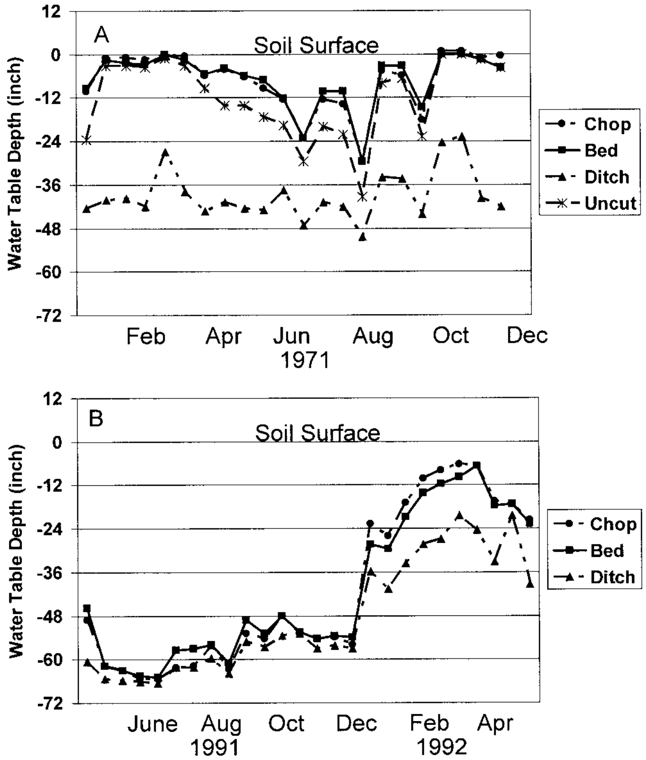

Figure 3. Effect of site preparation on depth of the water table in loblolly pine plantations on wet mineral flats in the Coastal Plain of Virginia. A) Water table depths from Jan. to Dec. 1971, during the 3rd year after planting. B) Water table depths from May 1991 to May 1992, during the 23rd and 24th years after planting.

Discussion

The results from this study suggest that the growth responses to site preparation treatments that improve soil aeration early in the rotation, such as ditching and bedding, decrease through longer periods of time. Early results from this study detected a significant increase in growth in the bed treatment and ditch treatment compared with the chop treatment (Langdon 1976, Andrews 1993). At age 5 years, trees in the ditch treatment averaged 10.3 ft compared with trees in the chop treatment that were 6.6 ft tall (Langdon 1976). By age 21 years, the differences were even more pronounced. Average height in the chop treatment was 38.3 ft compared with 44.4 and 46.3 ft in the bed treatment and the ditch treatment, respectively (Andrews 1993). At this age, stand basal area averaged 66 ft^2/ac in the chop treatment compared with 89 ft^2/ac in the bed treatment and 81 ft^2/ac in the ditch treatment (Andrews 1993). Total volume in the bed treatment was 1,844 ft^3/ac, which was significantly greater than total volume in the chop treatment (1,214 ft^3/ac) at age 21 years (Figure 2A). At age 33 years there were no differences in stand basal area (Table 1) or volume per acre among the site preparation treatments (Figure 2A).

Comparing the growth response at age 21 years to that at age 33 years indicates that the bed treatment followed a type C growth response relative to the chop treatment on these poorly drained soils (Figure 2A). A type C response is characterized by an initial increase in growth after treatment that declines through time (Hughes et al. 1979, Morris and Lowery 1988). Many other studies have observed large short-term response of loblolly and slash pine to bedding on poorly drained soils (Terry and Hughes 1975, Terry and Hughes 1978, Gent et al. 1986, Xu et al. 2000). However, only one other study has followed the response to bedding for a period of time comparable with that in the present study. Wilhite and Jones (1981) reported results similar to those in this study for a site with slash pine in Florida at age 35 years. They found that the growth response to bedding and drainage were greatest at age 17 years and then declined, typical for a Type C response.

Although height of the dominant pine in the ditch treatment was still greater than in the bed treatment and the chop treatment at age 33 years at this site, the growth response was less than that observed in loblolly pine after ditching in Pocosins in eastern North Carolina (Miller and Maki 1957, Maki 1960). However, the soils where Maki observed the dramatic, long-term response were organic soils (Histosols) that were much wetter than the mineral soils (Ultisols) present on these sites that are characterized as wet flats. A smaller, shorter-lived growth response similar to that in the present study was observed in slash pine after ditching on a mineral soil in Florida (White and Pritchett 1970). The growth response to ditching will likely be larger on wetter sites (Terry and Hughes 1978).

Water table data from the present study site offers an explanation for the decreased growth response through time (type C response) observed to bedding and ditching on these poorly drained mineral soils. After harvest, water tables tend to increase due to decreased rates of evapotranspiration (Aust and Blinn 2004). During the period from Jan. to Dec. 1969, water tables were at or near the surface of the soil for significant periods of time in the chop treatment and the bed treatment (Figure 3A). In contrast, water tables were consistently between 50 and 100 cm below the soil surface in the ditch treatment during this period. The increased volume of well-aerated soil in the ditch treatment would increase the rooting volume available to the seedlings and lead to increased growth (McKee and Shoulders 1974, Xu et al. 2000). Through time as the seedlings become established and grow, evapotranspiration rates increase and water tables tend to decrease (Aust and Blinn 2004). This was evident in the water table data collected during 1991 and 1992 (Figure 3B). Water tables were well below the soil surface in all three site preparation treatments throughout this period. Thus, through time the improved soil aeration and increased rooting volume resulting from site preparation treatments such as bedding and ditching will have less effect on tree growth. Consequently, a type C response was observed after bedding and ditching site preparation treatments when a longer rotation was studied. However, it should be noted that this study confirmed the results from most other studies of bedding that have found a relatively large growth response through at least 20–25 years. A significant increase in stand volume will likely occur in bedded plantations when rotations of this length are used.

Dominant height was 5–8 ft less in the bed treatment that was windrowed compared with the chop treatment and the ditch treatment that were not windrowed (Table 1). This translated to a significantly lower site index in the bed treatment (61 ft) compared with the chop treatment (66 ft) and the ditch treatment (68 ft). As part of the bed treatment, the slash and logging debris were pushed into windrows that were still approximately 2–3 ft tall at age 33 years. Large amounts of surface soil were displaced to the windrows during site preparation and the loss of nutrients associated with windrowing would have likely been large (Morris et al. 1983) and may have affected long-term productivity in this treatment. Fox et al. (1988) observed a similar drop in site index on an upland site in the Piedmont of North Carolina that was windrowed. Total volume in the bed treatment also was numerically the lowest, although differences among treatments in total volume were not significant. This is interesting because at age 21 years trees in the bed treatment were taller than in the chop treatment (Andrews 1993), and total stand volume in the bed treatment was greatest (Figure 2A). Although there were no significant differences in nutrient concentrations in the surface soil, it was interesting to again note that numerically the lowest values for P, K, Ca, and Mg were all in the bed treatment (Table 3). The decreased tree growth in the bed treatment was most notable in the check, P, and P + N fertilizer treatments where Ca was not added (Figure 1), suggesting that windrowing may have exacerbated the Ca deficiency on this site and led to the growth decline. Foliar nutrient concentrations followed the same trend, with numerically lower but not significantly different concentrations of P, K, Ca, and Mg in the bed treatment (Table 4). These data provide another cautionary note about the potential negative consequences to long-term site productivity of site preparation practices that include windrowing operations that displace large amounts of slash and soil (Burger 1996). However, the data from this study suggest that it may be possible to restore productivity on windrowed sites with appropriate fertilizer applications. Average tree height was significantly lower in the bed treatment relative to the other site preparation treatments in the unfertilized plots, but there was no difference in average tree height in bedded plots that were fertilized with N + P + lime (Figure 1).

The most remarkable response observed in this study was the long-term effect of the P + N + lime treatment on growth of loblolly pine. At age 33 years, 24 years after fertilization, trees in the P + N + lime treatment were larger and stand basal area and total volume were significantly greater than in the check or the P or P + N treatments. The effect of the P + N + lime treatment was even more pronounced at age 33 years than it was at age 21 years (Figure 2B). This is typical of a type A response that is characterized by a continued increase in growth through time of the treated trees compared with the controls (Morris and Lowery 1988). The elevated Ca and Mg in the soil and Ca in the foliage in the P + N + lime treatment relative to the other treatment attest to the effect of liming on soil fertility and tree nutrition at this site. This is the most likely cause of the observed growth responses because, although liming had a significant effect on soil pH, the pH change was relatively small. A limited number of studies have observed growth response in loblolly pine after liming, including the work of McCarthy and Davey (1976) on an organic soil in eastern North Carolina and Van Lear (1980) in the Piedmont of South Carolina. Others have found no effect of liming, such as the work of Moschler et al. (1970) in the Virginia Piedmont. A negative growth response was reported after liming on a Spodosol in the South Carolina Coastal Plain (Coultas et al. 1991). Clearly, the response of loblolly pine to liming depends on the specific soil properties at a location. Geology probably is important in determining soils that will be deficient in Ca. For example, soils with parent material containing mica will likely have high Ca concentrations and soils forming from silica quartz sand will have lower Ca concentrations (Adams 1984). Unfortunately, it remains difficult to determine the likelihood of a response to liming using conventional soil testing methods because there is no well-defined critical level of soil Ca. Foliage analysis may be a somewhat better predictor of the likelihood of a response to Ca. In this study, Ca concentrations in the trees in the check and the P-only treatment were below the proposed critical value of 0.12% for pine foliage (Fisher and Binkley 2000).

The lack of response to P or P + N fertilization on this site was somewhat surprising. Poorly drained Ultisols in the lower Coastal Plain generally are considered to be P deficient and numerous studies have observed large response after P or P + N fertilization on these of soils (Pritchett et al. 1961, Gent et al. 1986, Jokela et al. 1991, Jokela and Stearns-Smith 1993). Although the effect of P fertilization on soil P was still evident at age 33 years, extractable P levels in all the treatments, including the check, were above established critical levels (Wells et al. 1973). However, P concentrations in the foliage were below the established critical value of 0.11% for loblolly pine in all treatments except the P + N treatment. These data suggest that additional fertilization with P + N probably would have resulted in additional growth in this stand, provided that the apparent Ca deficiencies were corrected also.

Although site preparation and fertilization increased the growth in this study, the overall poor growth of loblolly pine in all the treatments suggests there are other factors at this site that continue to limit growth. Even in the ditch treatment that was fertilized with P + N + Lime, site index was only 68 ft and mean annual increment was only 160 ft^3/ac/year. Recent results from fertilization studies suggest that the one-time application of 100 lb/ac of N at age 9 years in this study was insufficient to achieve a large growth response (Allen 1987, Allen et al. 2005). Current fertilizer prescriptions for loblolly pine recommend 150–200 lb/ac of N plus 25 lb/ac of P applied every 6–10 years to maintain high leaf area and rapid growth (NCSFNC 2002). Larger and repeated applications of N, in combination with the P and lime applied in this study, that corrected apparent deficiencies of Ca, probably would have resulted in substantially more volume growth through the rotation. Although the growth response at this site was largely due to the added Ca, it probably would not have occurred without the addition of both P and N in addition to the Ca. The results emphasize the need for site-specific fertilization prescriptions that are designed to correct all the nutrient deficiencies that occur at a site. Additional work may be warranted to understand the extent of Ca deficiencies in loblolly pine, particularly in stands receiving repeated applications of N and P fertilizers.

Literature Cited

ADAMS, F. 1984. Crop response to lime in the Southern United States. P. 211–265 *in* Soil acidity and liming. Agronomy Monograph No. 12, 2nd ed., Adams, F. (ed.). ASA-CSSA-SSSA, Madison, WI. 380 p.

ALLEN, H.L. 1987. Fertilizers: Adding nutrients to enhance forest productivity. J. For. 85(2):37–46.

ALLEN, H.L., T.R. FOX, AND R.G. CAMPBELL. 2005. What's ahead for intensive plantation silviculture? South. J. Appl. For. 29(2):62–69.

AMATEIS, R.L., AND H.E. BURKHART. 1985. Site index curves for loblolly pine (Pinus taeda) plantations on cut-over site prepared lands. South. J. Appl. For. 9(3):166–169.

ANDREWS, L.M. 1993. Loblolly pine response to drainage and fertilization of hydric soils. MS Thesis, Virginia Polytechnic Institute and State University, Blacksburg, VA. 158 p.

AUST, W.M., AND C.R. BLINN. 2004. Forestry best management practices for timber harvesting and site preparation in the eastern United States: An overview of water quality and productivity research during the past 20 years (1982–2002). Water Air Soil Pollut. 4(1):5–36.

BALLARD, R. 1978. Effect of first rotation phosphorus application on fertilizer requirement of second rotation radiata pine. N. Z. J. For. Sci. 8(2):135–145.

BRADY, N.C., AND R.R. WEIL. 2002. The nature and properties of soils, 13th ed. Prentice Hall, Upper Saddle River, NJ. 960 p.

BURGER, J.A. 1996. Limitations of bioassays for monitoring forest soil productivity: Rationale and example. Soil Sci. Soc. Am. J. 60(6):1674–1678.

CAO, Q.V., AND H.E. BURKHART. 1980. Cubic foot volume of loblolly pine to any height limit. South. J. Appl. For. 4(4):166–168.

COMERFORD, N.B., M. MCLEOD, AND M. SKINNER. 2002. Phosphorus form and bioavailability in the pine rotation following fertilization: P fertilization influences P form and potential bioavailability to pine in the subsequent rotation. For. Ecol. Manage. 169(3):203–211.

COULTAS, C.L., Y.P. HSIEH, AND W.H. MCKEE JR. 1991. Loblolly pine seedling response to fertilizer and lime treatments on a Spodosol. Soil Sci. Soc. Am. J. 55(3):830–833.

DAVIS, D.E. 1959. Some effects of calcium deficiency on the anatomy of Pinus taeda. Am. J. Bot. 36(3):276–282.

DUBOIS, M.R., T.J. STRAKA, S.D. CRIM, AND L.J. ROBINSON. 2003. Costs and cost trends for forestry practices in the South. Forest Landowner, 34th manual ed. 62(2):3–9.

FISHER, R.F., AND D. BINKLEY. 2000. Ecology and management of forest soils, 3rd ed. John Wiley & Sons, New York, NY. 489 p.

FOX, T.R., L.A. MORRIS, AND R.A. MAIMONE. 1988. The impact of windrowing on the productivity of a rotation age loblolly pine plantation. P. 133–140 *in* Proc. of the 5th Biennial Southern Silvicultural Research Conf., Miller, J.H. (ed.). USDA For. Serv. Gen. Tech. Rep. SO-74. USDA Forest Service, Asheville, NC. 618 p.

FOX, T.R., E.J. JOKELA, AND H.L. ALLEN. 2004. The evolution of pine plantation silviculture in the southern United States. P. 63–82 *in* Southern forest science: Past, present, future, Rascher, H.M., and K. Johnsen (eds.). USDA For. Serv. Gen. Tech. Rep. SRS-75. USDA Forest Service, Asheville, NC. 394 p.

FREUND, R.J., AND R.C. LITTELL. 1981. SAS for linear models. A guide to the ANOVA and the GLM procedures. SAS Institute, Inc., Cary, NC. 231 p.

GENT, J.A. JR., H.L. ALLEN, R.G. CAMPBELL, AND C.G. WELLS. 1986. Magnitude, duration, and economic analysis of loblolly pine growth response following bedding and phosphorus fertilization. South. J. Appl. For. 10(3):124–128.

GENTLE, S.W., F.R. HUMPHREYS, AND M.J. LAMBERT. 1986. Continuing response of Pinus radiate to phosphate fertilizers over two rotations. For. Sci. 32(3):822–829.

GOMEZ, K.A., AND A.A. GOMEZ. 1984. Statistical procedures for agricultural research, 2nd ed. John Wiley & Sons, New York, NY. 680 p.

HARDING, R.B., AND E.J. JOKELA. 1994. Long-term effects of forest fertilization on site organic matter and nutrients. Soil Sci. Soc. Am. J. 58(2):216–221.

HARRIS, J.G., S. BALWIN, AND A.J. HOPKINS. 2004. The South's position in a global forest economy. For. Landowner 63(4):9–11.

HAUSER, J.W., W.M. AUST, J.A. BURGER, AND S.M. ZEDAKER. 1993. Drainage effects on plant diversity and productivity in loblolly pine (*Pinus taeda* L.) plantations on wet flats. For. Ecol. Manage. 61(1):109–126.

HUGHES, J.H, R.G. CAMPBELL, H.W. DUZAN SR., AND C.S. DUDLEY. 1979. Site index adjustments for intensive forest management at North Carolina. For. Res. Tech. Rep., Weyerhaeuser Co., New Bern, NC. 12 p.

JOKELA, E.J., H.L. ALLEN, AND W.W. MCFEE. 1991. Fertilization of southern pines at establishment. P. 263–280 *in* Forest regeneration manual, Duryea, M.L., and P.M. Dougherty (eds.). Kluwer Academic Publishers, Dordrecht, The Netherlands. 433 p.

JOKELA, E.J., AND S.C. STEARNS-SMITH. 1993. Fertilization of established southern pine stands: Effects of single and split nitrogen treatments. South. J. Appl. For. 17(3):135–138.

KUO, S. 1996. Phosphorus. P. 869–919 *in* Methods of soil analysis, Part 3. Chemical methods, Sparks, D.L., et al. (eds.). SSSA Book Series No. 5. Soil Science Society of America, Madison, WI. 1,390 p.

LANGDON, O.G. 1976. Study of effects of clearcutting, drainage, and bedding on poorly drained sites on water table levels and on growth of loblolly pine seedlings: Union Camp Drainage Study. USDA For. Serv. Progress Rep. 25 p.

LOWERY, R.F., AND D.H. GJERSTAD. 1991. Chemical and mechanical site preparation. P. 251–261 *in* Forest regeneration manual, Duryea, M.L., and P.M. Dougherty (eds.). Kluwer Academic Publishers, Dordrecht, The Netherlands. 433 p.

LYLE, E.S. 1969. Mineral deficiency symptoms in loblolly pine seedlings. Agron. J. 61(6):395–398.

LYLE, E.S. JR., AND F. ADAMS. 1971. Effects of available soil calcium on taproot elongation of loblolly pine (*Pinus taeda* L.) seedlings. Soil Sci. Soc. Am. Proc. 35(5):800–805.

MAKI, T.E. 1960. Improving site quality by wet-land drainage. P. 106–114 *in* 8th Annual forestry symposium: Southern forest soils, Burns, P.Y., (ed.). Louisiana State Univ. Press, Baton Rouge, LA. 132 p.

MCCARTHY, R., AND C.B. DAVEY. 1976. Nutritional problems of *Pinus taeda* L. (Loblolly pine) growing on Pocosin soil. Soil Sci. Soc. Am. J. 40(4):582–585.

MCKEE, W.H., AND E. SHOULDERS. 1974. Slash pine biomass response to site preparation and soil properties. Soil Sci. Soc. Am. Proc. 38(1):144–148.

MILLER, W.D., AND T.E. MAKI. 1957. Planting pine in pocosins. J. For. 55(9):659–663.

MORRIS, L.A., W.L. PRITCHETT, AND B.F. SWINDEL. 1983. Displacement of nutrients into windrows during site preparation of a flatwoods forest soil. Soil Sci. Soc. Am. J. 47(3):591–594.

MORRIS, L.A., AND R.F. LOWERY. 1988. Influence of site preparations on soil conditions affecting stand establishment and tree growth. South. J. Appl. For. 12(3):170–178.

MOSCHLER, W.W., G.D. JONES, AND R.E. ADAMS. 1970. Effects of loblolly pine fertilization on a Piedmont soil: Growth, foliar composition, and soil nutrients 10 years after establishment. Soil Sci. Soc. Am. Proc. 34(4):683–685.

NELSON, D.W., AND L. E. SOMMERS. 1996. Total carbon, organic carbon and organic matter. P. 961–1010 *in* Methods of soil analysis. Part 3. Chemical methods, Sparks, D.L., et al. (eds.). SSSA Book Series No. 5. Soil Science Society of America, Madison, WI. 1,390 p.

NCSFNC. 2002. North Carolina State Forest Nutrition Cooperative. 31st Annual Report, Department of Forestry, North Carolina State University, Raleigh, NC. 20 p.

PRITCHETT, W.L., AND N.B. COMERFORD. 1982. Long-term response to phosphorus fertilization on selected southeastern coastal plain soils. Soil Sci. Soc. Am. J. 46(3):640–644.

PRITCHETT, W.L., W.R. LLEWELLYN, AND K.R. SWINFORD. 1961. Response of slash pine to colloidal phosphate fertilization. Soil Sci. Soc. Am. Proc. 25(3):397–400.

SCHULTZ, R.P. 1997. Loblolly pine. The ecology and culture of loblolly pine (*Pinus taeda* L.). USDA For. Serv. Ag. Handbook 713.

SUCOFF, E.I. 1961. Potassium, magnesium, and calcium deficiency symptoms of loblolly and Virginia pine seedlings. USDA For. Serv. Sta. Pap. 164. 13 p.

TERRY, T.A. AND J.H. HUGHES. 1975. The effects of intensive management on planted loblolly pine (*Pinus taeda* L.) growth on poorly drained soils of the Atlantic Coastal Plain. P. 351–377 *in* Forest soils and forest land management, Bernier, B., and C.H. Winget (eds.). Les Presses de L'Universite Laval, Quebec, Canada. 675 p.

TERRY, T.A., AND J.H. HUGHES. 1978. Drainage of excess water: Why and how? P. 148–166 *in* Proc. On Soil moisture site productivity symp., Balmer W.E. (ed.). USDA For. Serv., Atlanta, GA. 400 p.

THOMAS, G.W. 1996. Soil pH and acidity. P. 475–490 *in* Methods of soil analysis. Part 3. Chemical methods, Sparks, D.L., et al. (eds.). SSSA Book Series No. 5. Soil Science Society of America, Madison, WI. 1390 p.

TIARKS, A.E., AND J.D. HAYWOOD. 1996. Site preparation and fertilization effects on growth of slash pine for two rotations. Soil Sci. Soc. Am. J. 60(6):1654–1663.

VAN LEAR, D.H. 1980. Effects of nitrogen, phosphorus, and lime on the forest floor and growth of pole-sized loblolly pine. Soil Sci. Soc. Am. J. 44(4):838–841.

WELLS, C.G., D.M. CRUTCHFIELD, N.M. BERENYI, AND C.B. DAVEY. 1973. Soil and foliar guidelines for phosphorus fertilization of loblolly pine. USDA For. Serv. Res. Pap. SE-110. 15 p.

WHITE, E.H., AND W.L. PRITCHETT. 1970. Water table control and fertilization for pine production in the flatwoods. Fla. Ag. Exp. Sta. Bull. 743. University of Florida, Gainesville, FL. 41 p.

WILHITE, L.P., AND E.P. JONES JR. 1981. Bedding effects in maturing slash pine stands. South. J. Appl. For. 5(1):24–27.

XU, Y.J., J.A. BURGER, W.M. AUST, AND S.C. PATTERSON. 2000. Response of surface hydrology and early loblolly pine growth to soil disturbance and site preparation in a Lower Coastal Plain wetland. N. Z. J. For. Sci. 30(2):250–265.

YOUNG C.E. 1972. Effect of clearcutting, drainage, and bedding on poorly drained loblolly pine stands on ground water levels and site productivity: Progress report. USDA For. Serv. SE For. Exp. Sta. Pap. FS-SE-1602. 27 p.