Reprinted from the *Soil Science Society of America Journal*
Volume 55, no. 3, May–June 1991
677 South Segoe Rd., Madison, WI 53711 USA

Loblolly Pine Seedling Response to Fertilizer and Lime Treatments on a Spodosol

C. L. Coultas, Y. P. Hsieh,* and W. H. McKee, Jr.

ABSTRACT

Loblolly pine trees (*Pinus taeda* L.) grow poorly on the Spodosols of the mid-Atlantic Coastal Plain. This greenhouse study was undertaken to determine the effects of N, P, S, micronutrients, and lime on the growth of Loblolly pine seedlings in the A1 horizon of a Lynn Haven fine sand (sandy, siliceous, thermic Typic Haplaquod). Nitrogen, and N-P in combination resulted in increased growth of the pine seedlings. A small application of $CaCO_3$ (2337 kg/ha) resulted in reduced growth and increased foliage necrosis. This negative effect was overcome by N applications. Micronutrients alone had little effect on growth and the foliage concentrations were adequate with all treatments. Sulfur treatment had a slight effect on plant growth but, with S, foliage N was increased from 17.5 to 19.0 g/kg. Aluminum concentrations were determined to be at nontoxic levels in this soil horizon. We postulate that the negative effect of $CaCO_3$ on plant growth was due to reduction of available N. The mechanism for this result has yet to be elucidated.

Spodosols in the mid-Atlantic Coastal Plain represent poor sites for growth of loblolly pine (Soil Conservation Service, 1974). The growing conditions suggest the presence of a nutrient deficiency or some physical barriers to the development of rapidly growing stands. Finer textured soils in the area have been shown to be responsive to P fertilizer (McKee and Wilhite, 1986); however, this response on the Spodosols has been erratic. In Florida, response to fertilization has been reported to be effective 75% of the time for slash pine (*Pinus elliottii* Engelm.) on these types of sites (Pritchett and Gooding, 1975). The use of limestone has also been investigated in Florida with insignificant results for both slash and loblolly pine (Coultas, 1973). Hence, it would appear that fertilization would be the most effective way to improve productivity for loblolly pine on these soils.

The objective of this study was to measure the growth and nutrient assimilation of loblolly pine with a range of added nutrient and lime combinations growing on soil taken from the A1 horizon of a Spodosol located in the lower Coastal Plain of South Carolina. This is the first to show that liming actually reduced the growth of trees in an acidic lowland Spodosol, and to establish that this negative effect was caused by the reduced N-supplying power of the soil.

MATERIALS AND METHODS

We collected soil from the A1 horizon (0–12 cm) of a Lynn Haven fine sand on the lower Coastal Plain of Charleston County, South Carolina. The soil was taken from four locations within a 33-m radius.

The vegetation on the site consisted of a sparse stand of loblolly, pond (*P. serotina* Michaux) and longleaf (*P. palustris* Miller) pines with common sweetbay (*Magnolia virginiana* L.) and swampbay (*Persea palustris* [Raf.] Sarg.). Gallberry (*Ilex glabra* [L.] A. Gray), *Vaccinium* spp., braken fern (*Pteridium aquilinum* [L.] Kuhn), broomsedge (*Andropogon* spp.), and fetterbush (*Lyonia lucida* [Lam.] K. Koch) were common in the understory. The 18-yr-old pines were 5 to 6 m tall and had yellowish-green foliage.

The soil samples were air dried, sieved through a 2-mm sieve, and mixed thoroughly. Subsamples were taken for moisture determinations. Soil moisture was determined by saturating four soil samples of known weight (669 g oven dried), allowing them to drain freely for 3 d, and reweighing. These soils held 0.67 kg H_2O/kg after draining freely from saturation for 3 d. Organic C was determined by the Walkley-Black method (Jackson, 1958, p. 134–182); N was determined by a modified micro-Kjeldahl procedure (Nelson and Sommers, 1980); extractable P was determined by a double-acid extraction method (Nelson et al., 1953). The organic C, total N, and extractable P of the soil were 68.5, 6.2, and 0.028 g/kg, respectively. The pH was 3.0 (1:1 H_2O) and 2.6 (1:2.5 KCl).

Soil (669 g) was placed in foam styrene plastic containers that had no drain holes. The following rates of nutrients (all in mg/kg) were applied in a partial factorial experiment: N, 47; P, 24; S, 13; Ca, 418; K, 18; Zn, 1.5; B, 1.0; Mn, 2.6; Mo, 1.0; and Cu, 2.6. The 16 treatments of the experiment were: N, P, S, L ($CaCO_3$), T (trace elements: Zn, B, Mn, Mo, and Cu), SL, TL, ST, NPL, NPT, NPS, STL, NPST, NPSL, NPSTL, and C (control). Potassium was applied to all the treatments and the control at 18 mg/kg level. Nitrogen was applied to the soil surface as urea. Phosphorus was applied as $Ca(H_2PO_4)_2 \cdot 2H_2O$ and mixed in the soil. Calcium and S were applied as $CaCO_3$ and elemental S, respectively, and mixed throughout the soil. The micronutrients were prepared in a single solution and applied to the soil surface. Sulfate salts of Cu, Zn, and Mn were used and H_3BO_3 and ammonium molybdate were the sources for B and Mo. Potassium was applied in solution to the soil surface as KCl. The control received no treatment except for K. There were four replicates of each treatment.

Loblolly pine seeds that had been harvested in the fall of 1987 (South Carolina "improved" lot 39-2-131-1-87-01) were stratified 6 wk at 4 °C, planted on acid-washed sand, covered with filter paper, and kept moist with distilled H_2O. Seedlings were transplanted 6 wk later. Transplanting was completed 11 Feb. 1988. Three seedings were planted into each container, and distilled, deionized water was applied at regular intervals to maintain the moisture level at 0.35 to 0.5 kg/kg range.

Seedlings were grown for 21 wk in the greenhouse. Temperature was normally held below 30 °C except for two short periods that reached 38 °C. Seeding heights were recorded biweekly in addition to the lateral shoots >2 cm in length and the number of plants with dead needles.

C.L. Coultas and Y.P. Hsieh, Florida A&M Univ., Tallahassee, FL 32307; and W.H. McKee, Jr., U.S. Forest Service, Charleston, SC. This research was supported, in part, by a grant from the U.S. Forest Service (no. 29-354). Received 20 Dec. 1989. *Corresponding author.

Published in Soil Sci. Soc. Am. J. 55:830–833 (1991).

Abbreviations: C, control; L, $CaCO_3$ (lime); T, trace elements: Zn, B, Mn, Mo, and Cu.

Seedlings were harvested 6 and 7 July 1988, divided into shoots and roots, dried at 65 °C for 3 d, and weighed. Plant material was ground to pass a 0.5-mm mesh screen and analyzed for nutrient contents. Nitrogen was determined by a modified micro-Kjeldahl procedure (Nelson and Sommers, 1980). A separate sample was dry ashed at 430 °C for 2 h, taken up in 0.3 *M* HNO_3, and analyzed for P by the molybdovanodate procedure (Jackson, 1958). Metals were measured by atomic absorption spectroscopy.

Analysis of variance was performed on all appropriate data. Mean separations were made using Tukey's test (Cochrane and Cox, 1957). Data with nonnormal distribution (numbers of plants with dead needles and shoots >2 cm) were analyzed after appropriate transformations.

RESULTS AND DISCUSSION

The response of shoot weight to the treatments can be organized into three groups (Fig. 1): those treated with N (including NPSTL, NPST, NPL, NPT, NPSL, NPS, and N) were significantly higher than the control; those treated without N or lime (including ST, T, S, and P) were not significantly different from the control; and those treated with lime but without N (including STL, TL, SL, and L) were significantly lower than the control. Obviously, there were significant N and lime effects and insignificant P, S, and T effects on the growth of loblolly pine seedlings in this experiment. Nitrogen increased the shoot weight, while liming decreased the shoot weight with respect to the control. With roots (Table 1), the ranking of mean yield (weight) by treatment was similar, except for NPS. Factorial analysis (omitting N and P) confirmed the depressing effect of L on shoot plus root growth. Mean shoot and root weight combined was 2.81 g without L, and 2.21 g with L. They were significantly different at the 0.05 probability level.

Height growth during an 8-wk period was greatest with some of the NP treatments (Table 1), although variability was greater than that of the shoot weight. Lime and the SL combination resulted in less shoot elongation. Mean growth rate was 8.9 cm without L, and 7.8 cm with L, which is significant at the 0.05 probability level.

Foliage N ranged from 16.5 g/kg (LT treatment) to 25.2 g/kg (NPS treatment) (Table 2). The NPS treatment resulted in higher foliage N than that of its limed counterpart. The NPSL, NPSTL, and NPL treatments did not increase foliage N levels above those treated with P, S, T, or L, or the control, however, suggesting that L reduced N uptake. Foliage N was reduced by L as indicated by factorial analysis. Average foliage N of the L-treated plants was 17.8 g/kg and for those without lime treatment it was 18.8 g/kg N, a significant difference.

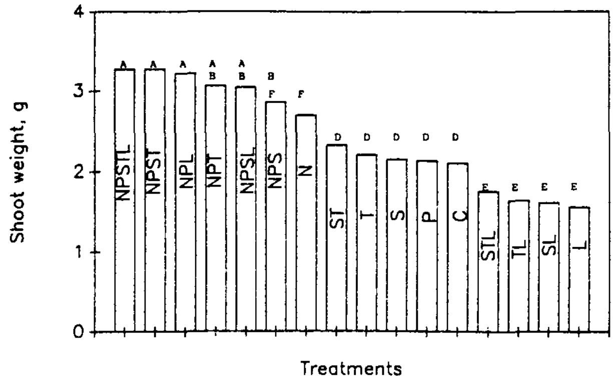

Fig. 1. The response of loblolly pine seedlings to the treatments of fertilizer and lime. T = trace elements, L = lime, C = control. A common letter on top of bars indicates no significant difference at the 0.05 probability level using Tukey's multiple-range test.

Foliage from the L-treated plants contained from 2.65 to 2.80 g Ca/kg. Those without L contained from 1.95 to 2.60 g Ca/kg. There were no significant differences in Ca contents among treatments, however. Magnesium concentrations ranged from 1.25 (SL) to 1.65 g/kg (NPS), with the NP treatment combinations resulting in high levels of Mg. Foliage P concentrations ranged from 1.05 (LT) to 1.91 g/kg (NPST) but treatment effects were not significant.

Plants tended to be nonresponsive to micronutrient treatments. Foliage copper ranged from 2.4 (N) to 8.8 mg/kg (SL) (Table 2), Zn ranged from 12.5 (C) to 21.0 mg/kg (STL) and Mn ranged from 24.6 to 69.9 mg/kg. These ranges were considered normal or slightly

Table 1. Root weight and shoot growth rate of loblolly pine seedlings subjected to various fertilizer and lime treatments.

Treatment†	Root	Shoot growth rate
	g	cm/8 wk
NPSTL	0.818a‡	10.4a
NPST	0.765ab	9.2abcd
NPL	0.765ab	10.0abc
NPT	0.672ab	10.2ab
NPSL	0.673ab	9.8abcd
NPS	0.577ab	8.4abcd
N	0.586ab	8.8abcd
ST	0.648ab	8.9abcd
T	0.609ab	8.7abcd
S	0.604ab	8.3abcd
P	0.647ab	8.8abcd
C	0.604ab	9.6abcd
STL	0.594ab	7.9bcd
LT	0.638ab	8.1abcd
SL	0.605ab	7.6d
L	0.519b	7.8cd

† L = $CaCO_3$, T = trace elements, and C = control.
‡ A common letter indicates no significant difference at the 0.05 probability level using Tukey's multiple-range test.

Table 2. Loblolly pine foliage analysis showing significant macro- and microelement responses.

Treatment†	N	Mg	Cu
	g/kg		mg/kg
NPS	25.2a‡	1.65a	4.7ab
N	24.0ab	1.30bc	2.4b
NPT	23.6abc	1.60ab	3.5b
NPST	23.2abc	1.60ab	4.0b
NPSL	20.6bcd	1.48abc	2.8b
NPSTL	20.0bcd	1.48abc	2.8b
S	19.7bcd	1.48abc	3.8b
SL	19.6bcd	1.25c	8.8a
ST	19.4cd	1.40abc	3.5b
P	19.2cd	1.42abc	5.0ab
NPL	19.0cd	1.45abc	3.0b
T	18.2d	1.30bc	3.5b
C	17.8d	1.32abc	3.2b
L	17.7d	1.27bc	6.4ab
STL	17.4d	1.27bc	5.5ab
LT	16.5d	1.37abc	7.0ab

† L = $CaCO_3$, T = trace elements, and C = control.
‡ A common letter indicates no significant difference at the 0.05 probability level using Tukey's multiple-range test.

lower than normal. Foliage from the SL, LT, L, and STL treatments contained about twice the Mn levels of those treated with NPL, ST, T, NPSTL, and N, although the differences were statistically not significant. Factorial analysis (without N and P) confirms the effect of L on foliage Mn concentrations (65.1 mg/kg with L and 40.1 mg/kg without L). Normally, lime reduces Mn uptake by increasing pH; however, lime had little effect on pH in this study. Foliage Fe concentrations ranged from 48.4 (T) to 112.8 mg/kg (NPT) and were not significantly different by treatments. The possibility that micronutrient treatment increased growth when combined with NP was substantiated with the observation that the combination increased weight of seedlings (shoots) from 1.86 to 1.98 g.

Sulfur applications had little effect on plant growth but increased foliage N from 17.5 to 19.0 g/kg. Zinc concentrations in both foliage and roots were increased by S applications, as was indicated by the factorial analysis. Foliage Zn was 18.7 mg/kg with S and 16.4 mg/kg without S. Roots contained 20.2 mg Zn/kg with S and 18.6 mg/kg without S.

Foliage Na ranged from 68.2 (C) to 147.3 mg/kg (NPSTL) with no significant treatment effects. Foliage K ranged from 6.6 to 8.2 g/kg with NPST-treated plants containing significantly less K than those treated with P, S, or ST.

Nitrogen concentrations in roots ranged from 8.7 to 13.6 g/kg (Table 3) with the N, NPS, NPST, and NPT treatments containing significantly higher levels of N than the NPL, LT, L, SL, or STL treatments. Limed treatments resulted in roots that contained lower levels of N than the no-L treatments (8.7 vs. 10.5 g/kg). Phosphorus concentrations ranged from 0.89 (STL) to 2.03 g/kg (L) and were unaffected by treatments. The LT-, NPSTL-, L-, STL-, NPSL-, SL-, and NPL-treated plants contained 1.25 to 1.50 g/kg Ca in their roots, which was significantly higher than those plants not treated with L (0.68–0.90 g Ca/kg, Table 3). Treatments had no significant effect on root Mg, which ranged from 0.60 to 1.65 g/kg.

Root Cu and Zn levels were unaffected by treatments. Copper concentrations ranged from 1.7 (NPS) to 9.2 mg/kg (L), while Zn varied from 13.8 (C) to 25.2 mg/kg (NPST). Factorial analysis indicated a significant positive effect of L on Zn concentration (20.7 mg/kg with L, 18.2 mg/kg without L). These ranges are similar to the Cu and Zn levels found in the foliage.

Table 3. Loblolly pine root analysis showing significant macro- and microelement response.

Treatment†	N	Ca	Mn	Fe
	g/kg		mg/kg	
NPS	13.6a‡	0.75b	17.8c	204.3bc
NPST	13.5ab	0.68b	46.0ab	186.7c
NPT	12.6ab	0.68b	47.8ab	209.5bc
N	12.6ab	0.90b	21.1c	223.0abc
ST	11.0bc	0.75b	53.0a	231.8abc
NPSTL	10.8bc	1.45a	38.0b	255.6abc
NPSL	10.5bc	1.32a	18.6c	265.0abc
P	10.4bc	0.80b	19.0c	253.0abc
C	10.3bc	0.70b	18.1c	256.3abc
S	10.3bc	0.78b	19.4c	238.7abc
T	10.3bc	0.75b	50.9ab	241.1abc
NPL	10.0c	1.25a	18.6c	228.4abc
LT	8.9c	1.50a	48.0ab	322.6a
L	8.8c	1.42a	21.7c	302.7ab
SL	8.7c	1.32a	21.3c	336.8a
STL	8.7c	1.38a	57.5a	260.8abc

† L = $CaCO_3$, T = trace elements, and C = control.
‡ A common letter indicates no significant difference at the 0.05 probability level using Tukey's multiple-range test.

Manganese concentrations in the roots ranged from 17.8 to 57.5 mg/kg (Table 3), which is slightly lower than that found in the foliage. There was not the same positive effect of L on Mn concentrations in the roots as there was with the foliage. Those treatments with the highest Mn levels were all treated with T. Iron concentrations ranged from 186.7 (NPST) to 336.8 mg/kg (SL). The SL and LT treatments resulted in higher Fe levels in the roots than the NPST, NPS, and NPT treatments.

At the end of the experiment, pH ranged from 2.8 (ST) to 3.0 (L, NPL, SL, LT, and STL). Lime caused a significant, though small, increase (0.1–0.2 unit) in pH.

Potassium in roots ranged from 4.3 (NPS) to 6.6 g/kg (P), with P treatment resulting in significantly higher K levels than C, N, NPL, NPS, NPSL, NPSTL, or NPT. Treatments had a highly significant effect on root Na. The NPL, NPS, NPSL, NPST, NPSTL, and NPT treatments contained from 1012 to 1348 mg Na/kg while the LT, S, SL, STL, and T treatments resulted in Na concentrations of <500 mg/kg. Potassium concentration in the roots ranged from 4.28 to 6.5 g/kg. The P-, STL-, and ST-treated plants contained significantly higher levels of K than those treated with NPS.

With such an extremely acidic soil, we were concerned that Al toxicity may have been a problem. We extracted the untreated soil (C) with 1 *M* KCl and found 123.7 mg Al/kg soil. The limed soil contained 93.4 mg Al/kg. We concluded from this that Al toxicity is not a problem with this soil (at least in the A1 horizon) and that L treatment reduced the extractable Al. Liming did not reduce the uptake of micronutrients in this case.

Several conclusions can be drawn from this experiment. Nitrogen has a favorable effect and lime has a depressing effect on the growth of loblolly pine seedlings in the surface horizon (A1) of a Lynn Haven loamy sand soil. Phosphorus, S, and T alone had no significant effect on the growth of the pine seedlings in this study. Nitrogen was the limiting factor of the seedling growth in the control. The results of soil chemistry in this experiment cannot explain the cause of the negative effect of liming on the growth of the pine seedlings. Since the N-supplying power in a forest soil is mainly through organic-N mineralization, we suspect that the negative effects of liming could have been linked to the soil microbiology. In a study of N transformations in acidic freshwater wetland soils of northern Florida, Hsieh and Coultas (1989) found that liming actually reduced the nitrification rate in most of the soils and the ammonification rate of some soils. If liming caused unfavorable changes in the microbiology of the soil, the N-supplying power of the soil could be substantially reduced and could cause reduction in growth of the seedlings. The reduced N-supplying power due to changes in soil microbiology was overcome by the N fertilization, as is evident in this study.

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