FERTILIZATION of LOBLOLLY PINE on two ALABAMA SOILS

Effects on Growth and Foliar Mineral Content

BULLETIN 370
JUNE 1966

AGRICULTURAL EXPERIMENT STATION
AUBURN UNIVERSITY

E. V. Smith, *Director* Auburn, Alabama

CONTENTS

FIRST PRINTING 3M, JUNE 1966

Fertilization of Loblolly Pine on two Alabama Soils: Effects on Growth and Foliar Mineral Content

DR. M. C. CARTER and E. S. LYLE, JR.
Department of Forestry

INTRODUCTION

SINCE WORLD WAR II there has been a great increase in public and private interest in forestry. This interest has manifested itself in increased acreages of artificial reforestation. The investment required for this reforestation has caused concern regarding the financial return to be expected. It is only natural for the investor to desire a quick and maximum return and this desire has led to an interest in forest fertilization since fertilization has proved to be quite profitable for agronomic crops.

Fertilization of forest nursery soils has been successfully practiced, as a necessity, for a number of years on a worldwide basis. Also, fertilizers have been successfully used in special cases such as forest tree seed production, Christmas tree production and for rehabilitation of badly depleted soils. However, the most useful application of fertilizer might well be in increasing volume growth and wood quality of trees after they have become established on a normal site. At present, this application is still within the experimental stage.

In general, the effect of readily available fertilizers on forest tree growth has been unpredictable and of short duration. Addoms *(1)*, in 1937 found great individual variation in growth rate of fertilized seedlings even though they were originally selected for uniformity of size. Several investigators *(5,7,10,16,17,18,21, 22,26,29)* have reported an increase in diameter growth of pine trees following fertilization, but no increase in height growth.

However, Gessel *(6)*, Heiberg *et al. (8)*, Hughes and Jackson *(11)*, Smith *(23)*, and Walker *(25)* have observed an increase in height as well as in diameter growth of pine trees following fertilization. A note of caution by Pritchett and Robertson *(20)* states that 300 pounds per acre of nitrogen or K_2O may reduce growth of newly planted pines on sandy soil.

There are a number of factors that cause variations in the response of pine trees to fertilization. One of the factors that has probably prevented an increase in growth is the greater demand on available moisture that occurs when the amount of undergrowth is increased by fertilization. Of course, this would affect newly planted seedlings to a much greater extent than it would established seedlings. Another factor has been the lack of knowledge concerning interrelations of nutrients and water in pines. Many fertilization studies undoubtedly have been carried out on soils where moisture was the limiting factor rather than nutrients. Pharis and Kramer *(19)*, working with loblolly seedlings in sand culture, found that nitrogen concentration above optimum for growth reduced drought resistance. Bensend *(2)* made the same discovery with jack pine seedlings. Leaching losses of applied nutrients on porous soils could also obscure a possible growth response to fertilization.

An exploratory research study dealing with fertilization of established loblolly pine seedlings was begun in March, 1960 to learn more about the relationship between soil fertilization, soil mineral content, foliage mineral content, and growth. Two locations were chosen for the study. One was a reasonably fertile Piedmont soil that had been in cultivation prior to planting trees. The other was a recently clearcut Coastal Plain soil of low fertility and no history of cultivation.

PROCEDURE

The better site was a Cecil sandy loam located in Chambers County in the Alabama Piedmont (habitat region III G) *(9)*. This site was an old field abandoned 2 years prior to establishment, without site preparation. The poorer site was a Eustis loamy sand located in Baldwin County in the Alabama Lower Coastal Plain (habitat region V LS-I) *(9)*. This site had no history of cultivation and the existing stand of longleaf pine had been clearcut with the remaining vegetation bulldozed and windrowed prior to planting with loblolly pine.

Both sites were machine planted with 1-year-old seedlings at an approximate spacing of 6 x 8 feet. The seed for both plantings were collected in and adjacent to the county in which the seedlings were planted. Survival after two growing seasons was good at both locations. Growth on the Piedmont site was excellent, with trees averaging 4.0 feet in height after two growing seasons. Growth on the Coastal Plain site was fair to poor, with an average height of 1.9 feet after second growing season. Figure 1 shows the relative difference in seedling growth between the two sites even though there is a one year age difference between stands.

During the winter following the second growing season, a 2^3 factorial experiment with two replications was established at each location. The eight plots in each replication were located along the contour on one chain centers. Each plot was circular, 0.05 acre in area, and the 9 trees nearest the plot center were tagged for sampling. The selection of sample trees was completely objective, even though a few individuals appeared weakened or deformed by fusiform rust (*Cronartium fusiforme*) and tip moth (*Rhyacionia frustrana*). Later, it appeared that trees having large stem cankers should have been omitted from the sample. However, mortality from all causes during the 2 years following original measurement consisted of only 3 trees of the 288 tagged.

Fertilizers were broadcast by hand during the month of March each year, Table 1. No attempt was made to incorporate the

FIGURE 1. The view at left shows seedlings on the Coastal Plain site at age 3 years and the view at right shows seedlings on the Piedmont site at age 2 years.

TABLE 1. CALENDAR OF TREATMENT AND DATA COLLECTION

	Year				
	1960	1961	1962	1963	1964
Piedmont					
Height growth	March	March	March	[1]	March
Diameter growth			October		
Treatment	March	March	March		
Foliage collection		October			
Soil collection	December				
Coastal Plain					
Height growth		March	March	March	March
Diameter growth				October	
Treatment		March	March	March	
Foliage collection			October		
Soil collection		December			

[1] The breaking off of terminals by an ice storm made the taking of height data in 1963 seem illogical.

materials into the soil. A flush of annual grasses resulted from the first application of nitrogen, Figure 2. Therefore, the amount of nitrogen applied was increased the second year to ensure an adequate supply for both trees and undergrowth. Nitrogen was applied at the rate of 150 pounds of ammonium nitrate per acre the first year and 300 pounds per acre per year the next 2 years.

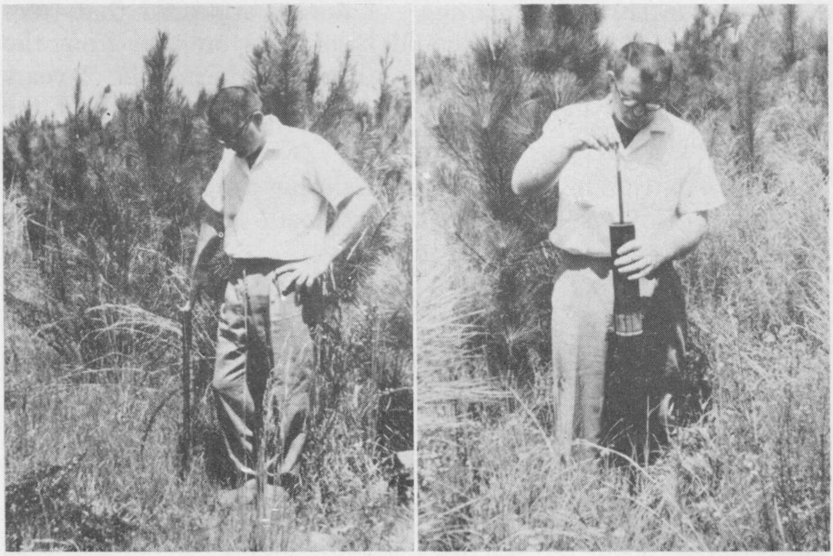


FIGURE 2. The plot on the right received nitrogen, phosphorous and potassium. Note the difference in amount of lesser vegetation between it and the left hand plot which recived no fertilizer.

Phosphorus was applied the first year only at the rate of 750 pounds of superphosphate (18-20% P_2O_5) per acre. Potassium was applied all three years at the rate of 125 pounds of muriate of potash (60% K_2O) per acre per year.

Using a push tube, soil samples were collected from the top 6 inches of soil. Nine cores were taken from each plot and composited during December following the first application of fertilizers, Table 1.

Available phophorous and potassium were extracted from soil samples by shaking 5-g. sample with 20 ml. of 0.05 N HCl and 0.025 N H_2SO_4 solution for 5 minutes. Phosphorous was then determined by the vanadomolybdophosphoric yellow color method in a nitric acid system. Potassium was determined by the usual flame photometer method. The Walkely-Black method of wet combustion was used for the organic matter determinations. Soil pH was measured by glass electrode in a soil to water ratio of 1:2.5. The Kjeldahl method was used to determine total organic and ammonium forms of nitrogen.

Foliage samples were collected during early October at the end of the second growing season following the first application of fertilizer, Table 1. Fully expanded, current year foliage from the terminal shoot or topmost whorl of lateral branches was collected since mineral content of this foliage has been considered best correlated with mineral uptake *(27,28)*.

Foliage samples were oven dried at 70° C. and ground in a Wiley mill. Total nitrogen was determined on a 0.1 g. sample by the Ranker salicylic acid-thiosulfate adaptation of the semi-micro Kjeldahl method using a Kemmerer-Hallett distillation unit. Two gram samples of oven-dry plant material were dry ashed at 525° C. and taken up in concentrated HCl. This solution was used for the determination of potassium by flame photometry and phosphorous by colorimeter reading of phosphomolybdic blue color.

Method of Data Analysis

Analysis of covariance was applied to the height growth data from the 2^3 factorial arrangement with height before treatment as the independent variable and height after treatment as the dependent variable. The effect of treatment on diameter growth, soil analysis, and foliage nutrient content was determined by analysis of variance.

TABLE 2. HEIGHT OF LOBLOLLY PINE BEFORE AND AFTER FERTILIZATION

Site	Height of trees[1]						
	With N	No N	With P	No P	With K	No K	Average
Coastal Plain	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*
Before fertilization, 1961	2.0	1.9	2.0	1.8	2.0	1.9	1.9
After 1 year, 1962	3.9	3.7	3.8	3.8	3.8	3.7	3.8
After 2 years, 1963	6.2	5.8	6.0	5.9	6.0	5.9	6.0
After 3 years, 1964	9.3	8.3[2]	9.0	8.6	9.0	8.6	8.8
Piedmont							
Before fertilization, 1960	3.9	4.0	3.8	4.1	3.9	3.9	3.9
After 1 year, 1961	7.3	7.3	7.3	7.3	7.3	7.3	7.3
After 2 years, 1962	12.6	12.2	12.6	12.5	12.3	12.3	12.4
After 4 years, 1964[3]	23.6	23.5	23.5	23.7	23.7	23.4	23.5

[1] All heights after treatment adjusted for height before treatment by regression.
[2] Effect of nitrogen significant at the 5 per cent level on Coastal Plain site after third year.
[3] Plantation was severly damaged by ice storm during winter of 1962-63. The Piedmont height measurements cannot be considered representative, since many of the taller trees were broken.

RESULTS AND DISCUSSION

Nitrogen applied as a fertilizer on the Coastal Plain site produced a significant increase in height growth after 3 years of fertilization, Table 2. There was no significant increase in height growth for the Piedmont site. Table 2 shows the possible beginnings of a nitrogen effect on height growth in the second year at the Piedmont site. However, an ice storm in 1963 caused many of the terminals to break off, thereby obscuring any effect of fertilization on height growth. An even stronger trend was shown for phosphorous at the Piedmont site in the second year but the ice storm again apparently obscured any effect by the fourth year.

TABLE 3. DIAMETER OF LOBLOLLY PINE, SIX INCHES FROM GROUND, AFTER 3 ANNUAL APPLICATIONS OF FERTILIZER

Site	Diameter of trees						
	With N	No N	With P	No P	With K	No K	Average
	In.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*
Coastal Plain[1]	2.6[2]	2.2	2.5	2.3	2.5	2.3	2.4
Piedmont[1]	4.5[2]	4.1	4.3	4.4	4.3	4.3	4.3

[1] Both plantations were 5 years of age when measured. Piedmont measurements taken in October 1962 and Coastal Plain in October 1963.
[2] Effect of nitrogen significant at the 1% level of both locations.

Nitrogen produced a significant increase in diameter growth at both sites after three annual applications of fertilizer, Table 3. These findings are in agreement with previously reported results *(4,13,26,29)*. No increase in diameter growth resulted from phosphorous or potassium. However, the effects of phosphorous and potassium may not appear as quickly as the effect of nitrogen and future measurements may disclose an increase resulting from these additives. Both phosphorous and potassium have been found to influence diameter growth of pine at other locations *(13,21,24)*.

The application of a nitrogenous fertilizer increased the percentage of nitrogen found in the foliage at both locations, Table 4. This result agrees with earlier findings in both greenhouse and field *(5,15,25,29)*.

There was a significant reduction of foliage phosphorous at the Piedmont site when nitrogen was added to the soil, Table 4. This was not true for the Coastal Plain site. A reduction in foliar phosphorous following nitrogen application is common in fruit trees, *(3)*. However, results with forest trees have been variable. Fowells and Krauss *(5)* reported a lowering of foliage phosphorous with high nitrogen levels, but other workers did not *(5,15,21,25,29)*. Cain *(3)* concludes that, while the phosphorous level on a dry weight basis may be reduced following nitrogen application, the total phosphorous per tree remains unchanged or increases slightly as a result of increased dry weight production following nitrogen application. In the present study, increased foliage production was apparent on trees

TABLE 4. FOLIAGE MINERAL CONTENT[1]

Site	Foliage mineral content						
	With N	No N	With P	No P	With K	No K	Average
Coastal Plain							
Nitrogen (%)	1.97[2]	1.57	1.71	1.84	1.81	1.74	1.77
Phosphorous (p.p.m.)	963	1032	1155[2]	840	1024	971	998
Potassium (%)	0.57[2]	0.47	0.52	0.52	0.60[2]	0.44	0.52
Piedmont							
Nitrogen (%)	1.45[2]	1.28	1.36	1.37	1.35	1.38	1.32
Phosphorous (p.p.m.)	626[2]	699	688	638	653	672	663
Potassium (%)	0.69	0.69	0.70	0.68	0.75[2]	0.64	0.69

[1] Samples collected in October after two annual applications of fertilizer.
[2] Indicates significant main effects at 5% level or higher.

receiving nitrogen or nitrogen plus phosphorous, hence Cain's *(3)* explanation may be applicable.

A significant increase in foliar potassium was found at the Coastal Plain site when a nitrogenous fertilizer was applied to the soil, but there was no increase at the Piedmont site. Fowells and Krauss *(5)* reported a lowering of foliar potassium in loblolly pine with an increase of nitrogen level in a sand culture solution, but Ingestad *(11)*, working with spruce, found an increase in foliar potassium with an increase of nitrogen level in nutrient solutions.

Addition of superphosphate to the Coastal Plain soil resulted in an increase in foliage phosphorous, Table 4. There was no increase at the Piedmont site. However, the Piedmont soil contained 8 p.p.m. available phosphorous before treatment, whereas the Coastal Plain soil contained none. Since Fowells and Krauss *(5)* found that 1 p.p.m. phosphorous in sand culture solution satisfied the demands of loblolly, the lack of significance in the Piedmont data is not surprising. Foliar potassium and nitrogen were unaffected by phosphorous application at both sites.

Foliar potassium content was increased at both sites when potassium fertilizer was added to the soil, Table 4. There was no increase in foliar phosphorus at the Coastal Plain site with increase in potassium supply.

The only first order interaction that was significant for both sites was the nitrogen plus phosphorous effect on foliar potassium content, Figure 3. When nitrogen and phosphorous were applied together, the foliar potassium content was reduced. However, the reduction was not to a level below that of the unfertilized trees. Larger trees probably meant more foliage per tree and, therefore, a greater dilution of the absorbed potassium and a possible explanation for the decrease in foliar potassium.

The nitrogen-phosphorous interaction was significant in the foliar nitrogen and foliar phosphorus data at the Piedmont site. Nitrogen applied to the soil without phosphorus caused foliar nitrogen to increase, Figure 4, but when nitrogen and phosphorous were applied together there was little change in foliar nitrogen content. Phosphorous alone increased foliar phosphorous, but nitrogen and phosphorous together did not increase foliar phosphorous more than nitrogen alone, Figure 5. Both of these

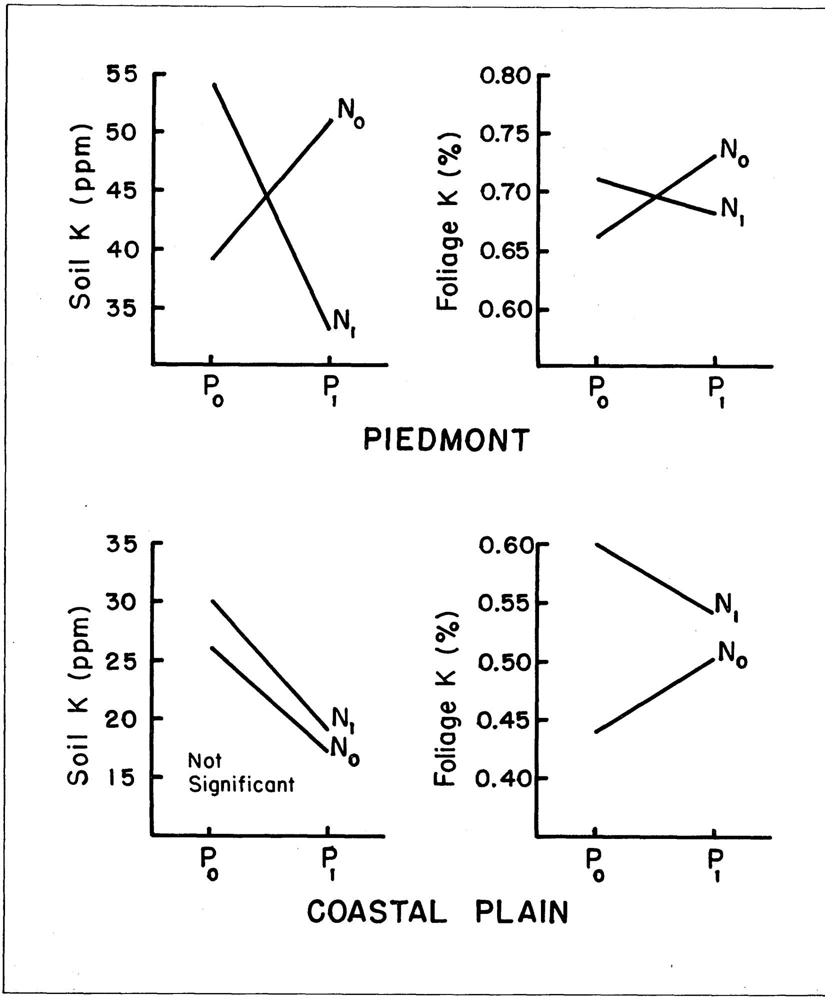


FIGURE 3. Interaction between nitrogen and phosphorous fertilizers and soil and foliar potassium contents at both sites.

interactions may have resulted from a growth dilution effect occurring when nitrogen and phosphorous were added together.

Soil fertilization with superphosphate reduced the amount of available soil potassium at the Coastal Plain site but not at the Piedmont site, Table 5. More potassium was most likely removed from the soil on the Piedmont site, but a greater potassium supplying power probably prevented a drop in available supply.

TABLE 5. SOIL ANALYSES FROM FERTILIZED LOBLOLLY PLANTATIONS[1]

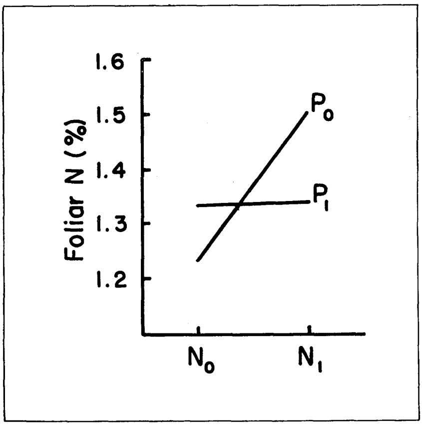
Site	Soil mineral content						
	With N	No N	With P	No P	With K	No K	Average
Coastal Plain							
Nitrogen (p.p.m.)	576	621	630	567	658[2]	539	598
Phosphorous (p.p.m.)	0.2	2.0	2.2	0	0.2	2.0	1.1
Potassium (p.p.m.)	25	22	18[2]	28	31[2]	15	23
Organic matter (%)	1.78	2.02	1.87	1.93	2.11	1.69	1.90
pH	5.0	5.1	5.0	5.1	5.1	5.1	5.1
Piedmont							
Nitrogen (p.p.m.)	522	484	502	503	508	498	503
Phosphorous (p.p.m.)	11	19	22	8	17	13	15
Potassium (p.p.m.)	43	45	42	46	57[2]	31	44
Organic matter (%)	1.00	0.98	1.01	0.97	1.05	0.93	0.99
pH	5.5	5.9	5.7	5.7	5.8	5.6	5.7

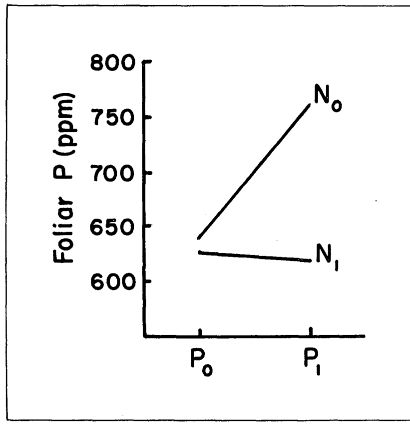
[1] Soil samples collected in December following first application of fertilizer.
[2] Indicates main effects significant at 5% level or higher.

Muriate of potash applied to soils gave an increase in soil potassium at both sites, Table 5. However, there was also an increase in soil nitrogen at the Coastal Plain site. It was noted by ocular estimate that plots given potassium alone or in combination contained more undergrowth. The greater amount of undergrowth would increase the organic matter of the soil, which is directly correlated with total nitrogen of the soil. The more complete shading by the larger trees of the Piedmont plots reduced the development of soil organic matter by inhibiting production of undergrowth.

There was an interaction between phosphorous and potassium that affected soil potassium at the Coastal Plain site, Figure 6. Application of potassium without phosphorous greatly increased soil potassium content, which was only slightly increased when phosphorous and potassium were both added. This effect seems logical, remembering that phosphorous alone decreased and potassium alone increased soil potassium, Table 5.

At the Piedmont site, the only soil interaction was the effect of nitrogen and phosphorous on soil potassium, Figure 3. Nitrogen or phosphorous applied alone increased soil potassium. However, when they were applied to the same plot, there was a reduction in soil potassium. This same interaction did not hold true on the Coastal Plain site, Figure 3. There was a tendency for nitrogen alone to increase soil potassium at both sites, whereas, phosphor-





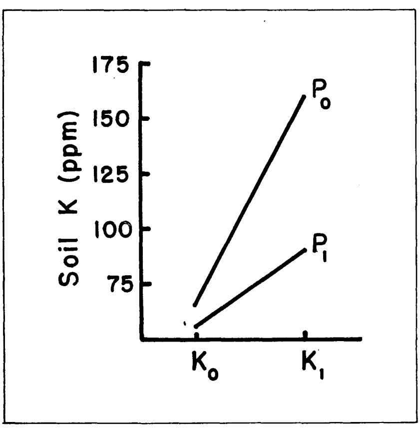


FIGURE 4. Interaction between nitrogen and phosphorous fertilizers and foliar nitrogen content at the Piedmont site. (Above left)

FIGURE 5. Interaction between nitrogen and phosphorous content at the Piedmont site. (Above right)

FIGURE 6. Interaction between phosphorous and potassium fertilziers and soil potassium content at the Coastal Plain site. (Left)

ous alone tended to cause an increase at the Piedmont site and a decrease at the Coastal Plain site.

CONCLUSIONS

Responses to fertilization in loblolly pine plantations were in general agreement with results obtained with horticultural or agronomic crops. From observation of all plots in the present study, it appears that total dry matter production was greatly increased by all fertilizer applications since the size and density of the foliage on the fertilized trees greatly exceeded that of the unfertilized trees. Also the increase in diameter growth at both sites and the increase in height growth at the Coastal Plain site resulting from nitrogen application indicates an increased dry weight production. Maki *(14)* obtained the same general results from nitrogen fertilization of loblolly pine, noting an increase in average diameter, basal area, needle production and total litter production. With most agricultural crops total dry weight or fruit production is the important response factor, whereas the growth parameter of major concern in young pine plantations has been height. Therefore, most of the response to fertilization is of little economic value according to present evaluation methods based on height growth.

Height growth of the plantations studied must be mainly limited by some factor other than nutrient supply; namely, soil moisture and physical properties. However, nitrogen supply apparently was below the level that the tree could utilize since some growth response followed the application of this element. Diameter growth was particularly responsive to nitrogen application and may be more closely related to nutrient supply than height growth.

The response to nitrogen fertilization was similar to usual response to thinning in that diameter growth increased while height growth changed very little. However, one difference must be remembered. Thinning, except in a severely stagnated stand, usually results in an immediate decrease in total volume growth per acre. Meanwhile, subsequent growth is concentrated on remaining trees, thus enabling them to reach merchantable size sooner than if no thinning were done. If fertilization continues to increase diameter growth at greater stand densities, it may hasten the movement into merchantable size with an increase in final volume per acre. Likewise, it may be possible to substitute fertilization for at least part of the thinning and obtain increased diameter growth on a greater number of trees per acre. This is, of course, speculative since the effect of fertilization upon volume per acre growth at different age and density classes has not been ascertained. Also, the persistence of fertilization effects is unknown. However, the unspectacular results of the present investigation must not be interpreted as indicating that fertilization cannot play an important role in forest management. Long term evaluation of fertilization effects under various conditions of site, size, and age class could lead to profitable future use of fertilizers in forest management.

SUMMARY

An exploratory experiment was designed to determine effects of fertilization on young established loblolly pine plantations at two different locations in Alabama. One location was a relatively fertile Piedmont soil and the other a relatively infertile Coastal Plain soil. The experimental design was a randomized complete block with a 2^3 factorial arrangement of treatments. Nitrogen was applied at the rate of 150 pounds of ammonium nitrate per acre the first year and 300 pounds per acre per year the next 2 years. Phosphorous was applied the first year only at the rate of 750 pounds of superphosphate (18-20% P_2O_5) per acre. Potassium was applied all 3 years at the rate of 125 pounds of muriate of potash (60% K_2O) per acre per year.

The following significant effects resulted from the use of fertilizers:

(1) Nitrogen produced an increase in height growth at the Coastal Plain site after 3 years of fertilization.

(2) Nitrogen produced an increase in diameter at both sites.

(3) Nitrogen increased foliage nitrogen concentration at both locations.

(4) Nitrogen reduced foliage phosphorous concentration at the Piedmont site.

(5) Nitrogen increased foliage potassium concentration at the Coastal Plain site.

(6) Phosphorous increased foliage phosphorous concentration at the Coastal Plain site.

(7) Potassium increased foliage potassium concentration at both sites.

(8) A nitrogen-phosphorous interaction affected foliage nitrogen and phosphorous concentrations at the Piedmont site. Nitrogen alone increased nitrogen concentration, but nitrogen and phosphorous together caused little change in nitrogen concentration. Phosphorous alone increased phosphorous concentration, but nitrogen and phosphorous together did not increase foliar phosphorous concentration.

(9) A nitrogen-phosphorous interaction at both sites affected foliage potassium. Nitrogen or phosphorous applied alone increased potassium concentration but together they reduced potassium concentration.

(10) At the Coastal Plain site, phosphorous fertilization reduced soil potassium content.

(11) Potassium fertilization increased soil nitrogen and potassium at the Coastal Plain site, but increased potassium only at the Piedmont site.

(12) A phosphorus-potassium interaction affected soil potassium at the Coastal Plain site. Potassium without phosphorous greatly increased soil potassium content, but only slightly increased it when phosphorous and potassium were added together.

(13) Soil potassium was affected by a nitrogen-phosphorous interaction at the Piedmont site. Nitrogen or phosphorous applied alone increased soil potassium content; however, they suppressed it when used together.

Since fertilization increases diameter growth, it may be possible to partially substitute fertilization for thinning as a means of bringing stands into merchantable diameter sizes. Fertilization would have the added advantage of not reducing the number of trees per acre at the time of treatment . Long term evaluation of forest fertilization effects under various conditions of site, tree age, tree size, and stand density could lead to an increased future use of fertilizers in forest management.

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to N. D. Pearce, Opelika, Alabama, and Carney Timber Lands, Atmore, Alabama, for providing the land and other assistance in the conduct of this work.

LITERATURE CITED

(1) ADDOMS, R.S. Nutritional Studies on Loblolly Pine. Plant Physiol. 12:199-205. 1937.

(2) BENSEND, D. W. Effect of Nitrogen on Growth and Drought Resistance of Jack Pine Seedlings. Tech. Bul. Minn. Agr. Expt. Sta. 163:1-63. 1943.

(3) CAIN, J. C. Plant Tissue Analysis. Part II: Observation on Antagonistic Effects in Leaf Analysis. Mineral Nutrition of Trees. pp. 63-70. School of For., Duke Univ. 1959.

(4) CURLIN, J. W. Response of Natural Stands of Shortleaf Pine to Thinning and Fertilization with Nitrogen and Phosphorous. S.S.S.A.P. 27:234-236. 1963.

(5) FOWELLS, H. A. AND KRAUSS, R. W. The Inorganic Nutrition of Loblolly Pine and Virginia Pine with Special Reference to Nitrogen and Phosphorus. For. Sci. 5:95-112. 1959.

(6) GESSEL, S. P. Progress and Problems in Mineral Nutrition of Forest Trees. Tree Growth, pp. 221-235. The Ronald Press Co., N.Y. 1962.

(7) GILMORE, A. R. AND LIVINGSTON, K. W. Cultivating and Fertilizing a Slash Pine Plantation: Effects on Volume and Fusiform Rust. J. of For. 56:481-483. 1958.

(8) HEIBERG, S. O., MADGWICK, H. A. I., AND LEAF, A. L. Some Longtime Effects of Fertilization on Red Pine Plantations. For. Sci. 10:17-23. 1964.

(9) HODGKINS, E. J. Southeastern Forest Habitat Regions Based on Physiography. Auburn Univ., Agr. Expt. Sta., For. Dept. Series No. 2, Auburn, Ala. 1965.

(10) HOEKSTRA, P. E. AND ASHER, W. C. Diameter Growth of Pole-size Slash Pine After Fertilization. J. of For. 60:341-342. 1962.

(11) HUGHES, R. H., AND JACKSON, J. E. Fertilization of Young Slash Pine in a Cultivated Plantation. U.S. For. Serv. Southeastern For. Expt. Sta. Paper 148, 14 pp. 1962.

(12) INGESTAD, T. Studies on the Nutrition of Forest Tree Seedlings. II Mineral Nutrition of Spruce. Psysiologia Plantarum 12:568-593. 1959.

(13) MAKI, T. E. Effect of Fertilizers on the Growth of Loblolly Pine Plantations. Unpublished manuscript, N.C. St. Univ., Raleigh. 1955.

(14) MAKI, T. E. Some Effects of Fertilizers on Loblolly Pines. 7th Intern. Cong. of Soil Sci. 3:363-375.

(15) MCGEE, C. E. A Nutritional Study of Slash Pine Seedlings Grown in Sand Culture. For. Sci. 9:416-469. 1963.

(16) MCGREGOR, W. H. D. Fertilizer Increases Growth Rate of Slash Pine. U.S. For. Serv. S.E. For. Expt. Sta. Notes No. 101. 1957.

(17) MERGEN, F. AND VOIGT, G. K. Effects of Fertilizer Applications on Two Generations of Slash Pines. S.S.S.A.P. 24:407-409. 1960.

(18) MOEHRING, D. M. Speeding Up Growth of Loblolly. Forest Farmer. 23:9, 13-14. 1964.

(19) PHARIS, R. P. AND KRAMER, R. J. The Effects of Nitrogen and Drought on Loblolly Pine Seedlings. For. Sci. 10:143-150. 1964.

(20) PRITCHETT, W. L. AND ROBERTSON, W. K. Problems Relating to Research in Forest Fertilization with Southern Pines. S.S.S.A.P. 24:510-512. 1960.

(21) PRITCHETT, W. L. AND SWINFORD, K. R. Response of Slash Pine to Colloidal Phosphate Fertilization. S.S.S.A.P. 25:397-400. 1961.

(22) ROTH, E. R. AND EVANS, T. C. Effect of Soil Amendments on Growth of Shortleaf Pine. J. of For. 56:215-216. 1958.

(23) SMITH, L. F. Rapid Growth of Slash and Loblolly Pines on Cultivated Plots. Tree Planter's Notes. No. 46 pp 9-10. 1961.

(24) VIAMIS, J., BISWELL, H. H. AND SCHULTZ, A. M. Nutrient Responses of Ponderosa Pine Seedlings. J. of For. 55:25-28. 1951.

(25) WALKER, L. C. The Effects of Water and Fertilizer on Loblolly and Slash Pine Seedlings. S.S.S.A.P. 26:197-200. 1962.

(26) WALKER, L. C. AND YOUNGBERG, C. T. Response of Slash Pine to Nitrogen and Phosphorous Fertilization. S.S.S.A.P. 26:399-401. 1962.

(27) WELLS, C. G. AND METZ, L. J. Variation in Nutrient Content of Loblolly Pine Needles With Season, Age, Soil and Position on the Crown. S.S.S.A.P. 27:90-93. 1963.

(28) WHITE, D. P. Foliar Analysis in Tree Nutrition Research. First North American Forest Soils Conference, pp. 49-52. Agr. Expt. Sta. Mich. St. Univ. East Lansing. 1958.

(29) ZAHNER, R. Fertilizer Trials With Loblolly Pine in Southern Arkansas. J. of For. 57:812-816. 1959.