USDA Forest Service Research Paper SE-110 October 1973

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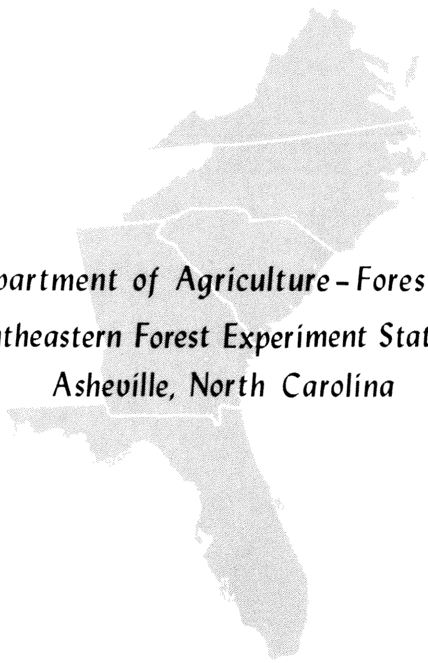

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Southeastern Forest Experiment Station
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INTRODUCTION

There are extensive areas of soils deficient in phosphorus (P) in the southeastern Coastal Plain. Previous studies have shown that the growth rate of southern pine on some sites has been increased by P fertilization. In one case, under conditions of low soil and needle P, loblolly pines (*Pinus taeda* L.) at age 3 were 6.8 feet tall on plots fertilized with 25 or 50 pounds of P per acre and only 3.7 feet tall on nonfertilized plots (Wells and Crutchfield 1969). Average tree height at age 5 was 14.8 feet on the same P-fertilized plots and only 8.0 feet on the nonfertilized plots. Results of this type demonstrate the practical aspect of P fertilization where needed.

Soil tests and foliar analysis are means to detect soils which need P fertilization. Foliar analysis has been more reliable than soil tests for prediction of increased growth of southern pines from P fertilization (Pritchett 1968; Wells and Crutchfield 1969). A reliable soil test would have more utility than needle analysis because soils could be tested and fertilizers applied before or soon after planting. The use of needle analysis is not possible on some sites because loblolly pine trees are not available before regeneration or they are suppressed to such an extent that needle content would not be indicative of soil fertility. Soil samples are also easier to collect than needles, especially from large trees. In assessing fertility, information on more than one element is desirable, and such information can be derived from soil tests. One deficient element may cause foliage to be high in other elements which will not be in adequate supply when deficiency of the first element is corrected. A high level of needle N (nitrogen) has been observed when P is deficient, because tree growth is not sufficient for the available N to be utilized. This imbalance in nutrients is the basis of the N/P ratio as a guide to P fertilization (Raupach 1967).

Generally, soils in the Southeast are acid, and P is found in combinations with Fe, Al, Ca, and organic matter. Various chemical forms of P are adsorbed on soil particles, and these forms are believed to be important sources of P for plants. A soil test should extract a quantity of P correlated with the amount plants can obtain from the soil. In turn, the results of soil tests, when properly interpreted, would indicate the need for fertilization. Soil P tests have been developed with different chemical extractants in order to measure the so-called "available P" to plants. In certain instances, good correlations have been found between the amount of available P extracted and the response of crops to P fertilization.

Two widely used P extractants, the Bray No. 2 (0.1$\underline{N}$ HCl + 0.03$\underline{N}$ NH_4F) (Bray and Kurtz 1945) and the one adapted by the North Carolina Soil Testing Laboratories[1] (0.05$\underline{N}$ HCl + 0.025$\underline{N}$ H_2SO_4), are considered effective for extraction of available P. Loblolly pine obtains adequate P on soils low in fertility by standards used for agronomic crops. Therefore, it is often suggested that ectomycorrhizae or certain root characteristics enable this pine to obtain P from relatively insoluble forms. Total P has been used as a guide for P fertilization of pine in Australia (Baur 1959). In trials with different extractants, P extracted by 1.0$\underline{N}$ NH_4OAc (pH 4.8) was more highly correlated with response to P fertilization of slash pine in Florida than was total P or P extracted by several other solutions (Pritchett and Llewellyn 1966). In the South Carolina Piedmont, P extracted by 0.002$\underline{N}$ H_2SO_4 (pH 3.0) and 0.1$\underline{N}$ HCl + 0.03$\underline{N}$ NH_4F was more closely related to P in loblolly pine needles than was total P (Wells 1965). Loblolly pine on Tatum silt loam in the Virginia Piedmont did not respond to P fertilization in 10 years after fertilization even though soil P was only 4.5 kg./ha. by 0.05$\underline{N}$ HCl + 0.025$\underline{N}$ H_2SO_4 extraction (Moschler, Jones, and Adams 1970). These results indicate that a P extractant stronger than the 0.1$\underline{N}$ HCl + 0.03$\underline{N}$ NH_4F solution might have merit.

Before a soil test can be used for recommendation of fertilization, field studies must show that the test will be useful for the differentiation of soils into groups in which pine will and will not respond to fertilization. For both foliar analysis and soil tests, knowledge of the physiology of the plant and of the physical and chemical nature of the soils, along with a good understanding of the ecology of each site, are necessary in order to relate the laboratory analysis to tree growth. The response from correction of a specific nutrient deficiency is often limited by factors about

[1] Soil Testing Division of the North Carolina Department of Agriculture, Raleigh, N.C

which less information is available, such as excessive water in the Coastal Plain or lack of water in the Piedmont, competition from weeds, and deficiencies of other elements. For these reasons, results of field research are variable and more information is desirable if fertility and management practices are to be continually improved.

The purpose of the present investigation was to evaluate and calibrate soil tests and foliar analysis as methods to predict response to P fertilization. These evaluations were intended to serve as the basis for more dependable recommendations on the use of soil tests and foliar analysis for loblolly pine in the Piedmont and Coastal Plain.

METHODS

Field

Tree height was measured and soil and needle samples were collected from 3-year-old loblolly pine on fertilization plots in the Coastal Plain of South Carolina and the Piedmont of Virginia and South Carolina. A soil sample was collected from each plot by compositing 15 to 20 sampling-tube cores from the 0- to 8-inch depth. A composite needle sample was collected from 10 to 20 trees per plot by taking five fascicles from upper lateral branches of the first flush of the previous spring.

There were 11 studies in the Coastal Plain with applications of 20 to 50 pounds of P per acre; these studies were comprised of 40 paired plots with and without P. In the Piedmont, there were nine studies with P rates of 50 to 200 pounds per acre; these studies were comprised of 52 paired plots. All plots contained at least 20 trees for measurement inside similarly treated border areas. The studies differed in design, consisting of experiments with one to three P rates and from two to five replications but in all cases containing paired plots with and without P. The P fertilizer was usually broadcast on the soil surface at about planting time. In one Piedmont study, fertilizer was placed in the closing holes when the seedlings were hand planted; in one Coastal Plain study, fertilizer was applied in 4-foot-wide bands and the plots were then bedded. Planting was both by hand and machine on beds in the Coastal Plain and on site-prepared land in the Piedmont. The P source was triple superphosphate except for a source comparison with normal superphosphate in one study.

At age 3, a relatively short time in terms of response after P application and planting, no significant differences in response were found for rates, application techniques, or P sources. Because no differences were found, rates, methods, and P sources were used in the same way to test for response to P fertilization.

The Piedmont sites were on upland soils which were moderately well drained to well drained. Studies in the Coastal Plain were all on bedded sites previously prepared as required for a satisfactory bedding operation. These soils ranged from very poorly drained in a Coxville loam to moderately well drained in a Chipley loamy sand.

Laboratory

Soil samples were air-dried and ground to pass a 2-mm. mesh sieve. Extractions for available P and cations were made by shaking 5 ml. (approximately 5 g.) of soil measured in a calibrated scoop and 50 ml. of extracting solution for 5 minutes and then filtering. Available P extractions were made with the North Carolina (N.C.) (0.05$\underline{N}$ HCl + 0.025$\underline{N}$ H_2SO_4), Bray No. 2 (0.03$\underline{N}$ NH_4F + 0.1$\underline{N}$ HCl), and 5$\underline{N}$ HCl solutions. Total P was estimated by digesting 2 g. of soil in 6 ml. of a 1:1 mixture of 60-percent $HClO_4$ and 98-percent H_2SO_4 for 2 hours on a semi-micro-Kjeldahl apparatus (Ng 1970). Exchangeable K, Ca, and Mg were extracted with $\underline{N}$ NH_4OAc at pH 7 and Al by nonbuffered $\underline{N}$ KCl.

Needle samples of 0.5 g. were ashed in a muffle furnace at 450° C. for 4 to 6 hours. After ashing, 2 ml. of concentrated HCl were added and evaporated without boiling. Just as the samples reached dryness, they were removed from the hotplate and 20 ml. of 0.4$\underline{N}$ HCl plus 0.2-percent La solution were added. After 4 hours and two intermittent stirrings, the solution was poured into vials and the residue was allowed to settle for at least 16 hours.

Phosphorus was determined in the plants by the colorimetric vanadomolybdate method and in the soil extractants by molybdenum blue. Cations were determined by an atomic absorption spectrophotometer, N was determined by Kjeldahl, and soil C was determined by the Walkley-Black procedure (Jackson 1958).

Statistical

Correlations, regressions, and plotting methods were used to determine the relationships among soil and needle variables and tree height. A response index to P fertilization was calculated by the formula

$$\text{Response index} = \frac{\text{Height of trees on P-fertilized (P+) plots}}{\text{Height of trees on nonfertilized (Po) plots}} \times 100$$

Response index was then related to soil and needle variables.

RESULTS AND DISCUSSION

Application of P fertilizer consistently increased needle P in both the Piedmont and Coastal Plain. Tree height at age 3 was significantly increased by P fertilization on several Coastal Plain sites. A response to P was indicated in certain Piedmont sites, although it was not statistically significant at the 10-percent level. Without application of P (Po plots), soil P (N.C.) and needle P were correlated with height at age 3 in the Coastal Plain. On Po plots, significant correlation coefficients were found between height at age 3 and p.p.m. of soil P by the N.C. extractant (R^2 = 0.46) (fig. 1) and between height at age 3 and percentage of P in the needles (r^2 = 0.31) (fig. 2). Either of these two methods will predict the expected tree height at age 3. On the basis of these relation-

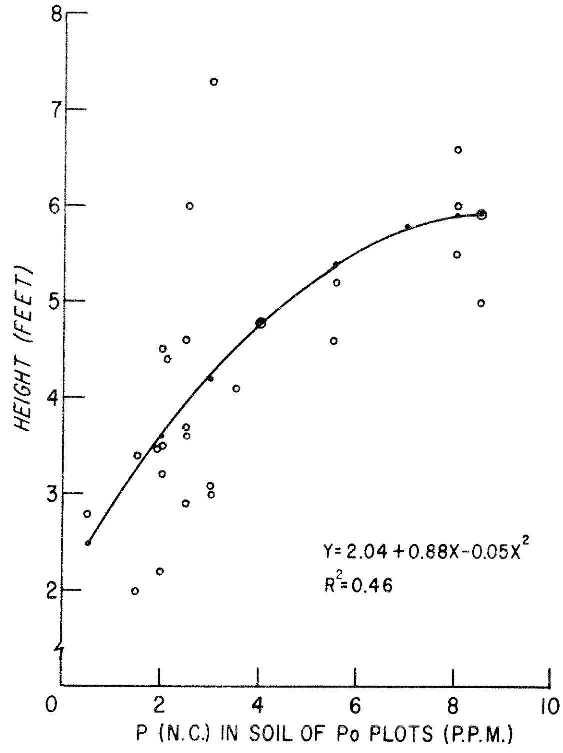


Figure 1.--Relationship between soil P (N.C.) and height of loblolly pine at age 3 on the nonfertilized (Po) plots in the Coastal Plain.

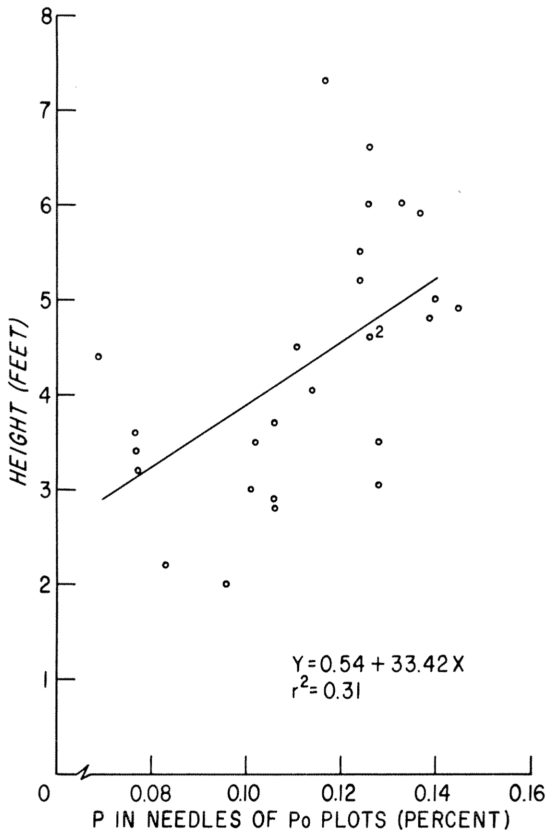
ships between soil or needle P and tree height, the effects of P fertilization can be evaluated to determine the critical level of soil or needle P below which P fertilization will increase growth and above which growth will not be increased by P fertilization.

Piedmont

For the Piedmont studies, correlation coefficients (r) between soil P and tree height at age 3 and between needle P and tree height were less than the 0.37 required for significance at the 5-percent level. The r for relationships between height and phosphorus predictor variables of Po plots in the Piedmont were: needle P, -0.14; soil P (N.C.), -0.34; soil P (Bray No. 2), -0.30; soil P (5N HCl), -0.30; and total soil P, -0.31. The r for relationships between tree height and other variables were: fascicle weight, 0.67; needle N, -0.14; needle K, 0.22; needle Ca, -0.37; needle Mg, -0.64; needle Mn, -0.06; needle Zn, -0.11; needle Cu, -0.61; needle Fe, -0.14; needle Al, 0.26; soil K, -0.25; soil Ca, -0.49; soil Mg, -0.30; soil Al, 0.70; soil N, 0.36; and soil C, 0.65.

Interesting speculations can be developed concerning the negative correlations between height and P and the positive correlations between height and Al. Further research is required to establish cause-and-effect relationships for these data. Without a meaningful relationship between P in the soil or needles and tree height, or a clear growth increase from P fertilization, we are without a basis for prediction of response to P fertilization in the Piedmont. Therefore, most of this report deals with data from the 11 studies in the Coastal Plain.

Figure 2.--Relationship between percentage of P in needles and height of loblolly pine at age 3 on the nonfertilized (Po) plots in the Coastal Plain.



Coastal Plain

Tree Height and Soil and Needle Variables

On Coastal Plain sites, a significant correlation was found between tree height and several parameters (table 1). Generally the r was positive for height on Po plots with soil P by N.C. and Bray No. 2 extractants. Needle P and fascicle weight showed strong relationships with height.

On the P+ plots, correlations were negative between height and extractable soil P (both N.C. and Bray No. 2) and needle P; but there were strong positive correlations with total soil P and soil N, K, Al, C, and C/N ratio. Height and C and C/N ratio were probably correlated because C and N are correlated and N was related to height. The shift from positive to a lower negative r between height and extractable soil P (N.C., Bray No. 2, 5N HCl) on the P+ plots suggests that, when P was applied to a P-deficient soil, the P need was satisfied, and one or more other factors became growth limiting. The strong positive r for the relationship between height and soil N indicates that N would be the next most limiting factor. Work reported for slash pine in Florida shows a response of young trees to N (Pritchett and Smith 1972). Soil K, Al, and total P were positively correlated with C and N. These relationships provide an explanation of the positive correlations between these elements and height on P+ plots.

Table 1.--Correlation (r) of soil and needle variables with height and response to P at age 3

Variable	Height on--			Response to P[4]
	Po plots[1]	P+ plots[2]	P+ plots[3]	
	r			
Soil P				
N. C.	0.54*	-0.30	0.10	-0.48*
Bray No. 2	.62*	-.38*	.39*	-.27
5N HCl	.40*	-.30	.47	-.19
Total soil P	.31	.65*	ND	-.16
Needle				
P	.56*	-.19	-.29	-.75*
N	.18	.14	.53*	.12
K	0	-.26	-.30	-.24
Ca	.05	-.51*	-.65*	-.56*
Mg	-.16	-.43*	-.65*	-.39*
Mn	-.11	-.42*	-.54*	-.31*
Al	.20	-.38*	-.38*	-.54*
Cu	.07	-.12	.03	-.03
Zn	-.17	-.32	-.16	-.07
Fe	-.18	-.13	ND	ND
Na	.29	.28	ND	ND
Fascicle weight	.58*	.06	ND	ND
N/P	-.29	.39*	.57*	.64*
Soil				
N	.02	.75*	.75*	.44*
K	0	.54*	.54*	.41
Ca	.38*	.02	.02	-.27
Mg	.20	.23	.23	.05
Al	-.29	.61*	.61*	.58*
pH	.29	-.28	-.29	-.37*
C	.04	.72*	.72*	.40*
C/N	0	.69*	.69*	ND

[1]Height of Po plots correlated with soil and needle variables of the same plots.
[2]Height of P+ plots correlated with soil P and needle variables of P+ plots and soil N, K, Ca, Mg, Al, pH, and C of Po plots of the replicate.
[3]Height of P+ plots correlated with soil and needle variables of paired Po plots.
[4]Response to P fertilization correlated with soil and needle variables of paired Po plots.

*Significant at the 5-percent level or greater. ND = not determined.

Levels of Soil and Needle P

The height of trees on the various Po plots at age 3 ranged from 2 to 7 feet (fig. 1). The range in height for a given P level in the soil or needles is caused by factors other than the P influence on height. Other soil factors which enhance growth are correlated with soil P and jointly contribute to good height growth. When the data for the Po plots are considered, it seems desirable to have a P level of about 7 p.p.m. in the soil (N.C.) and 0.13 percent in the needles (figures 1 and 2). Because many factors affect growth, it would be unsafe to assume that fertilization to increase soil P to 7 p.p.m. or needle P to 0.13 percent would consistently produce trees 6 feet tall at age 3.

Response to fertilization is the real test for fertilizer need under existing soil conditions. Figure 3 shows that a response to P fertilization is likely if needle P is 0.10 percent or less. When needle P was 0.09 percent or less on Po plots, the height was about 80 percent greater on the P+ plots than on the Po plots. The regression for response to P fertilization as a function of needle P is highly significant, with an R^2 (coefficient of determination) of 0.60. These results agree well with the critical foliar level of 0.11 percent previously established for needles of loblolly pine 1 year after planting (Wells and Crutchfield 1969).

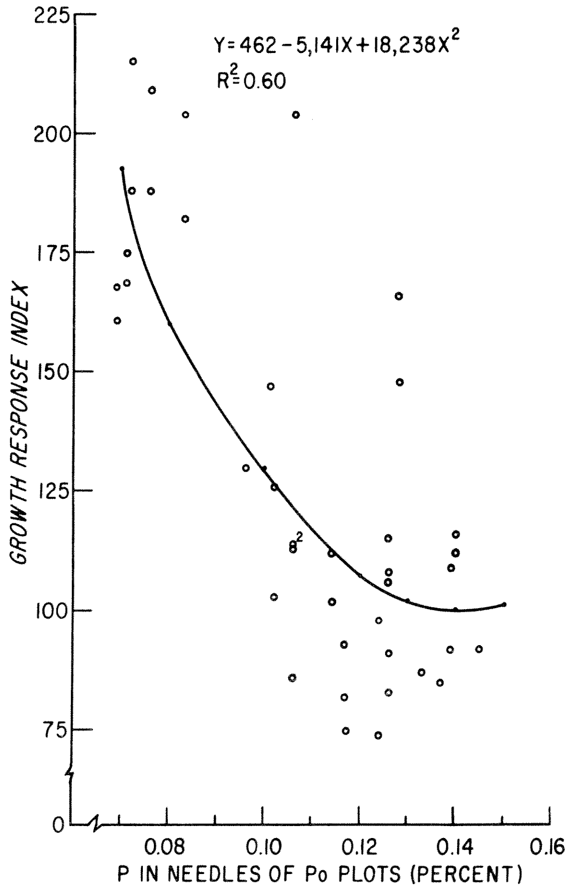


Figure 3.--Growth response index at age 3 after application of 20 to 50 pounds of P per acre in relation to P in needles of Po plots of the same replicate.

The relationship between soil P (N.C.) and response to P fertilization was not linear (fig. 4). Neither did the plotted data fit the second-order regression as used by Pritchett (1968) to predict the response of slash pine to P fertilization. However, figure 4 shows a useful separation of plots on the basis of the N.C. extractant for soil P. The Cate and Nelson (1971) procedure for partitioning data on soil test correlations into two classes was applied to our data to determine the critical level of soil P (N.C.). The procedure is to split the data into two groups by using successive tentative critical levels to ascertain that particular critical level which will maximize overall predictive ability (R^2), with the means of the two groups as the predictor values.

By the Cate and Nelson procedure, the maximum R^2 of 0.38 was obtained when soils with 2.3 p.p.m. or less of P formed a group with a mean response index of 158--or a response of 58 percent. The mean response index was 108 for plots with greater than 2.3 p.p.m. of P in the

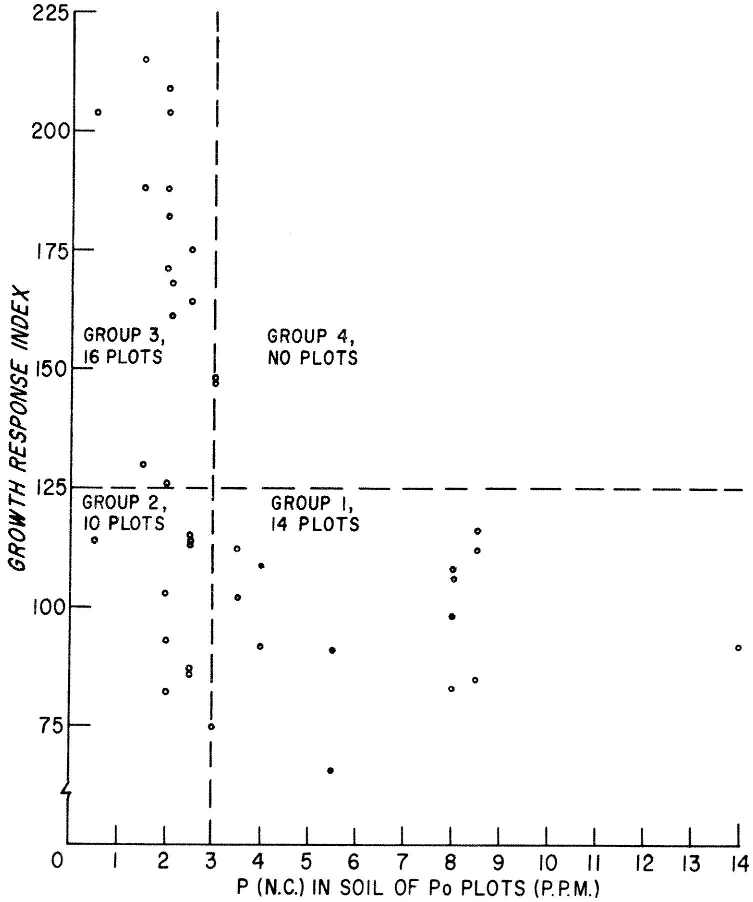


Figure 4.--Growth response index at age 3 after application of 20 to 50 pounds of P per acre in relation to soil P (N.C.) of Po plots of the same replicate. See text for explanation of the control lines and the various groups of plots.

soil. When the two groups were partitioned at 3 p.p.m. of P, the mean response indices were 145 for the soils at 3 p.p.m. or less and 98 for those greater than 3 p.p.m., and the R^2 value was 0.33.

Growth response index was less than 120 on soils with more than 3 p.p.m. of soil P. Drawing in broken control lines in figure 4 at 3 p.p.m. of P and 125 growth response index breaks the data into four groups:

Group 1--soils with over 3 p.p.m. of P and no growth response

Group 2--soils with 3 p.p.m. of P or less and no growth response

Group 3--soils with 3 p.p.m. of P or less and a good growth response

Group 4--soils with over 3 p.p.m. of P and good growth response.

There were no plots in Group 4. On the basis of this classification, 3 p.p.m. of P (N.C.) is the critical level of soil P. The several plots in Group 2 show that, on some soils, trees do not respond to P fertilization even when soil P is very low. However, none of the plots with soil P greater than 3 p.p.m. responded to P fertilization, and this lack of response makes possible the exclusion from fertilization of part of the soils where fertilization will not improve tree growth. Further investigation of reasons for no response to P on some plots in Group 2 is warranted.

Factors Preventing Response on Soils Low in P

There are two possible reasons for the lack of response to P on the plots with 3 p.p.m. or less of P: (1) An adequate supply of P was available to the trees although the soil test was very low, or (2) other factors limited growth and thus prevented the trees from responding to P. There were probably two or three plots that fell in category (1). Most of the plots would be in (2). An analysis of factors limiting response to P was pursued by comparing the soil properties of the plots in each of the three groups in figure 4 (table 2). Notice that when Group 2 (plots low in P but not responding) is compared with Group 3 (plots low in P and responding), needle P is higher on Po and P+ in Group 2. This difference accounts for the somewhat better correlation between needle P and response index than between soil P and response index. Application of P tended to decrease needle N in Group 3 because of improved growth and the dilution process. Needle Mn and Al are greater in Group 2 than in Group 3, but Al is still higher in Group 1 where growth was good. Danielson[3] found that Mn, Fe, and Al accumulated in greater concen-

[3]Danielson, R. M. The effect of soil fumigation on seedling growth, mycorrhizae and the associated microflora of loblolly pine (*Pinus taeda* L.) roots. 1966. (M.S. Thesis, N.C. State Univ. at Raleigh, Dep. Soil Sci., 148 pp.)

trations in loblolly pine seedlings which grew more rapidly as a result of soil fumigation. Group 2 differs from both Groups 1 and 3 in soil N. This indication that soil N was limiting growth is in agreement with the positive correlation between height and soil N on P+ plots (table 1), as discussed earlier. Total evaluation of data in table 2 indicates that N deficiency and possibly other factors prevent trees in plots of Group 2 from responding to P fertilization.

Table 2.--Characteristics of plots by response group

Variable	Treatment	Group 1[1] Soil P > 3 (N. C.) No response	Group 2[2] Soil P ≤ 3 No response	Group 3[3] Soil P ≤ 3 Good response
Height, ft.	Po	5.2	4.4	3.2
	P+	5.1	4.1	5.6
Soil P (N. C.), p.p.m.	Po	7.4	2.0	2.0
	P+	24.8	28.8	10.1
Needle P, percent	Po	0.128	0.114	0.094
	P+	0.136	0.129	0.119
Needle N, percent	Po	1.39	1.40	1.41
	P+	1.39	1.38	1.32
Needle K, percent	Po	0.54	0.43	0.46
	P+	0.48	0.44	0.42
Needle Ca, percent	Po	0.235	0.295	0.220
	P+	0.247	0.287	0.228
Needle Mg, percent	Po	0.100	0.132	0.104
	P+	0.111	0.119	0.113
Needle Mn, p.p.m.	Po	177	303	167
	P+	179	274	185
Needle Al, p.p.m.	Po	678	592	485
	P+	600	686	625
Needle Cu, p.p.m.	Po	4.2	4.0	4.0
	P+	4.2	3.7	3.9
Soil N, percent	Po	0.151	0.061	0.222
Soil K, p.p.m.	Po	39	32	49
Soil Ca, p.p.m.	Po	303	180	97
Soil Mg, p.p.m.	Po	41	23	26
Soil Al, p.p.m.	Po	123	170	313
Soil pH	Po	4.7	4.5	4.5
Soil P (total), p.p.m.	Po	143	68	121
	P+	152	121	188
Soil C, percent	Po	2.64	1.56	3.83

[1]14 paired plots.
[2]10 paired plots.
[3]16 paired plots.

Comparison of Tests for Soil P

The N.C., Bray No. 2, and 5N HCl extractions were used as a series of intensities to extract acid-soluble or available P. All three solutions extract Ca-P, adsorbed P, and portions of Fe- and Al-P. Perchloric acid-H_2SO_4 digestion yields estimates of total P, although it does not extract all of the P in certain soils.

A range in P extracted was obtained by the dilute acid extractions (table 3). The correlation was high between the P extracted by the N.C. and Bray No. 2 extractants in both Coastal Plain and Piedmont soils. Phosphorus extracted by 5N HCl was well correlated with that extracted by the N. C. extractant in the Piedmont but not in the Coastal Plain. Soil organic matter was higher and organic P was also higher in the Coastal Plain than in the Piedmont, as indicated by the high correlation ($r = 0.91$) between total P and C. Because 5N HCl extracts mineral P more readily than organic P, a higher correlation was found between 5N HCl-extractable P and total P in the Piedmont than in the Coastal Plain.

Table 3.--Correlation coefficients and means and ranges for different P extractions of 60 Coastal Plain and 35 Piedmont Po (nonfertilized) soils

Extraction	Bray No. 2	5N HCl	Total P	Mean	Range
		r		p.p.m.	
COASTAL PLAIN					
N.C.	0.82*	0.32*	0.29*	3.2	0-14
Bray No. 2		.32*	.48*	5.9	1-36
5N HCl			.11	14.2	2-70
Total P				119	54-443
PIEDMONT					
N.C.	.75*	.86*	.40*	4.6	0-36
Bray No. 2		.39*	.13	8.7	2-71
5N HCl			.69*	23.1	2-267
Total P				161.8	97-506

*Significant at the 5-percent level or greater.

Phosphorus by the N.C. and Bray No. 2 extractants was correlated at the 1-percent level with height at age 3, and P extracted with 5N HCl was correlated with height at age 3 at the 5-percent level (table 1). As a predictor of response, the N.C. extractant appeared to provide better separation of plots which would respond to P fertilization than did the other extractants. This superiority was indicated by the plotted data and by the fact that the response to P fertilization was more highly correlated with P extracted by N.C. (r = -0.48) than with P extracted by Bray No. 2 (r = -0.27), as indicated in table 1.

CONCLUSIONS

Soil P by the N.C. extractant and percentage of P in needles are useful for the prediction of loblolly pine response to P fertilization in the southeastern Coastal Plain. A lack of response to P fertilization in the Piedmont studies prevents development of guides for that region. Needle content of 0.10 percent P and values of soil P (N.C.) of 3 p.p.m. (6 lb./acre) were critical levels above which tree height at age 3 was not increased by P fertilization and below which P fertilization usually increased tree growth.

Several site factors should be considered in application of fertilization guides. In forestry operations, planting areas are relatively large, and the soil varies considerably. Variability within a plantation was demonstrated by a response to P on some replicates and no response on others within a study area of a few acres. As the trees grow older and their P requirements increase, a P response may occur on more soils and on soils with a soil-test value greater than 3 p.p.m. Competition from weeds and possibly other factors affecting growth will change as the trees become larger, and still more plots may respond to P application. Phosphorus fertilization is expected to increase growth of loblolly pine on some soils when soil P is 4 p.p.m. or less by the N.C. extractant. On the basis of these considerations, phosphorus fertilizer would be applied when soil P tests (N.C.) are 4 p.p.m. or less (8 lb./acre, assuming 2 million lb. of soil per acre in the 0- to 8-inch depth) on prepared Coastal Plain soils where growth conditions such as moisture and N supply are favorable.

The N. C. soil extractant for P compares well with the Bray No. 2 for the estimation of tree height at age 3 in the Coastal Plain. The N.C. extractant appears to provide better separation of sites where trees would respond to P fertilization than do the Bray No. 2, 5N HCl, and total-P extractions. At least eight states routinely use the N.C. extractant for soil P.[3] This uniformity offers an opportunity for improved standardization and calibration of soil tests as the use of soil testing in forestry increases.

In several paired plots, trees failed to respond to P fertilization even though soil P (N.C.) was below the critical level of 3 p.p.m. The applied P was available, as indicated by the increased P level in the needles on fertilized plots, but growth was still unsatisfactory, indicating that other limiting factors prohibited response to P.

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[3] Procedures for State soil tests may vary with respect to soil solution ratios, calculations, and the reporting of results. The N.C. test is normally made by State Soil Testing Laboratories by shaking 5 $cm.^3$ of soil and 25 ml. of extractant for 5 minutes, followed by filtering and analysis.

Nitrogen probably limited tree growth and, thus, response to P on some sites. On other sites, the lack of correlation between soil P by the tests used and the availability of soil P to trees accounts for errors in prediction of response to P fertilization. Continued study of the methodology of soil tests, tree physiology, and broader ecological relationships should produce considerable improvement in application of soils information to forest management.

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Several established studies of phosphorus fertilization in 3-year-old plantations of loblolly pine were measured for tree height and sampled for soil tests and needle analysis in order to relate soil and needle content to response to fertilization. Soil tests with the extractant adopted by the North Carolina Soil Testing Laboratories and percentage of P in needles were useful for prediction of tree response to P fertilization in the southeastern Coastal Plain but not in the Piedmont. Needle content of 0.10 percent P and values of the above-named extractant of 3 p.p.m. were critical levels above which tree height at age 3 was not increased by P fertilization and below which P fertilization usually increased tree growth. The data indicated that N influenced growth and limited response to P fertilization on some sites.

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