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Effects of Shallow Water Tables on Height Growth and Phosphorus Uptake by Loblolly and Slash Pines

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SUMMARY

In southern Mississippi, the heights of loblolly and slash pines at age 20 were positively correlated with the phosphorus content of the foliage and with depth in the soil to gray (chromas ≤2) mottles. Slash pine was taller than loblolly at equivalent levels of foliage phosphorus, but the rate of height increase as foliage phosphorus increased was the same for both species. Neither species was productive when the winter water table was at the surface. Phosphorus soil tests were not useful in predicting height even though phosphorus was a growth limiting nutrient. As the available phosphorus content of the soils studied is very low, the soil depth or volume of soil available for root exploration is more important than small differences in soil phosphorus.

Additional keywords: Gray mottles, phosphorus soil test, soil-site, soil water.

INTRODUCTION

During our evaluation of moisture related variables associated with 20-year heights of the four major southern pine species (Shoulders and Tiarks 1980), we encountered wide variations in tree heights among plots in an area of uniformly high summer rainfall in southern Mississippi. The variations were not related to rainfall, slope, or potential available soil moisture in the subsoil. Since climate was essentially uniform throughout the problem area and average rainfall exceeded optimum levels, we reasoned that differences in soil aeration or nutrient status might be affecting growth. To test our hypothesis, we related 20-year heights of dominant and codominant loblolly (*Pinus taeda* L.) and slash (*P. elliottii* Engelm var. *elliottii*) pines to levels of nitrogen, phosphorus, potassium, calcium, magnesium, sodium, manganese, and aluminum in foliage and to selected soil parameters not included in the previous investigation.

METHODS

Nine plantations of the larger study (Shoulders 1976, Shoulders and Tiarks 1980) were included in the current evaluation. They are in a 1000 km^2 area located near McHenry, Mississippi, where annual rainfall averages about 175 cm and mean warm season rainfall (April through September) exceeds 99 cm. The plantations originally contained 27 plots of each species. Of these, the survival on 17 loblolly and 25 slash pine plots was sufficient to provide reliable growth data through age 20.

Twenty-year heights of at least 10 dominant and codominant trees on each plot were measured during the winters of 1973-74, 1974-75, and 1975-76. Soil and foliage were sampled in January 1978.

Foliage samples were current-year needles from branches in the top one-third of the canopy of 10 dominant or codominant trees per plot. The needles were dried at 70°C and ground to pass through a 2-mm screen. Nitrogen was determined by the Kjeldahl method (Jackson 1958). Phosphorus, potassium, calcium, magnesium, sodium; manganese, and aluminum were determined on samples that had been dry ashed at 450 °C and taken up in $0.3N$ HNO_3. Phosphorus was determined by the ascorbic acid method (John 1970). The other elements were analyzed by atomic absorption spectrophotometry.

Soil samples consisted of a composite of 10 subsamples of the top 10 cm from each plot. The soil was air dried and passed through a 2-mm sieve. Organic phosphorus was determined by the ignition method (Saunders and Williams 1955) using a temperature of 550 °C and $0.2N$ H_2SO_4 as the extractant. The phosphorus extracted by $0.2N$ H_2SO_4 from the unignited sample used in the organic phosphorus determination was also considered to be an estimate of available phosphorus (Walmsley and Cornforth 1973). Other procedures used to measure available phosphorus were shaking the soil with $0.03N$ NH_4F + $0.1N$ HCl for 15 minutes (Jackson 1958) and shaking with $1N$ NaOH for 16 hours (Humphreys and Pritchett 1972). Phosphorus intenqity was determined by equilibrating 5 g of soil with 50 ml of water for 18 hours (Humphreys and Pritchstt 1972). Phosphorus equilibrium concentration was defined as the natural log of the phosphorus concentration after shaking 2 g of soil with 100 ml of solution which had an initial concentration of 0.25 µg of phosphorus/ml for 16 hours.

Soil series designations and soil profile descriptions of each plantation were made by Soil Conservation Service personnel in January 1981 (table 1). Depth to average winter water table was estimated from depth to gray mottles (chroma of 2 or less) (Soil Survey Staff 1975), except for Atmore, Smithton, and one soil whose series was not designated. The depth to average winter water table was taken to be 0.0 cm for these three soils based on observation of the water table, because organic matter coatings masked other colors. The profile of the unnamed soil has the characteristics of the Susquehanna series (Vertic Paleudalf, fine, montmorillonitic, thermic), except water accumulates on the surface during wet periods.

For statistical tests, the level of significance was preset to 0.05.

RESULTS

The height of the trees at age 20 was significantly correlated with the nitrogen, phosphorus, and aluminum concentrations in the needle samples (table 2) of both species. Height was also significantly correlated with calcium concentrations in slash needles and sodium in loblolly samples. Because of the high correlation between height and foliar phosphorus, the relationship between other elements and helght were possibly masked. Therefore the residuals, or the differences between actual heights and the predicted heights, from the Phosphorus regression were also related to the concentrations of the remaining elements. (table 2).

Table 1. — *Soil series, the/r classification, and measured depth to gray mottles or dominately gray horizons for the nine plantations studied*

Soil series	Classification[1]	Depth to gray mottles
		------- cm -------
Atmore	Pllnthic Paleaquults, coarse-loamy, slllceous, thermlc	0
Escambia	Pllnthaqulc Paleudults, coarse-loamy, slllceous, thermlc	25
Malbis	Pllnthlc Paleudults, fine-loamy, slllceous, thermlc	61
Poarch	Plinthlc Paleudults, coarse-loamy, siliceous, thermlc	150
Saucier	Plinthaquic Paleudults, fine-loamy, slllceous, thermlc	58
Smithton	Typic Paleaquults, coarse-loamy, slllceous, thermlc	0
Series not designated	....	0

[1] Soil survey staff. 1980. Classification of soil series of the United States, Puerto Rico, and the Virgin Islands. Unpublished report. U.S. Dep. Agrlc. Soil Conservation Service.

The nitrogen relationship was negative, meaning the lower nitrogen concentrations were In samples from the tallest stands. This may be due to a dilution effect with nitrogen in sufficient supply at the prevailing environmental conditions. Also, the range in concentrations measured (table 2) are above critical limits proposed by Pritchett and Gooding (1975).

Phosphorus concentrations were positively correlated with height. Slash pine was taller than loblolly at a given level of phosphorus concentra-

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Table 2. *-Range of nutrient concentrations in current years foliage and correlation* ***of the*** *concentrations with* ***height*** **at** *age 20 and with residuals from fitting phosphorus to height regression*

Element	Range in concentration for both species	Correlation			
		With height		With residuals	
		Slash	Lobioily	Slash	Lobioiiy
	........--mg/g---------	..... ---------------r---------------------			
Nitrogen	9.0-16.2	-0.55'	-0.84'	-0.30	-0.53"
Phosphorus	0.4-0.85	0.88'	0.80'	.....	.....
Potassium	1.7-4.4	0.28	0.20	0.01	-0.14
Caiclum	0.73-2.5	0.54*	0.25	0.11	-0.02
Magnesium	0.59-1.18	0.08	0.43	0.11	-0.11
Sodium	0.23-0.61	-0.34	-0.82*	-0.12	-0.53'
Manganese	0.08-0.47	0.29	0.04	0.15	0.22
Aluminum	0.24-0.86	0.77'	0.80*	0.20	0.37

*Correlation significant at 0.05 level.

tion in the needles (fig. 1), indicating that slash pine utilizes phosphorus more efficiently. Concentrations of phosphorus in foliage were below the critical level of 0.09 percent for slash (Pritchett and Gooding 1975). Therefore, the relationship between phosphorus and height is linear. The curve should begin to flatten, however, as the concentration exceeds the critical level.

Aluminum is not considered to be an essential element for tree growth. The high correlation between height and alumlnum concentration is probably due to aluminum and phosphorus occurring together in the soil, either in solution or as an aluminum-phosphorus complex. The correlation between aluminum and the residuals from the regression of phosphorus to height is not significant, supporting this interpretation.

While calcium is an essential plant nutrient, the relationship between calcium In foliage and height of slash pine probably is coincidental. Coastal Plain soils ordinarily contain sufficient calcium to sustain pine growth (Shoulders and McKee 1973) and calcium content of needles was not significantly related to residuals from the phosphorus-height equation.

The negative relationships of loblolly pine heights and of residuals from the phosphorus-height equation to sodium concentrations in needles suggest that a dilution of sodium in tissue accompanied a positive growth response to higher phosphorus levels in the needles.

Potassium, magneslum, and manganese were not correlated with growth. However, the levels measured are not considered to be deficient (Pritchett and Gooding 1975, Leaf 1973).

The soil variable most strongly correlate! with tree height at age 20 was the depth to gray mottles or to a seasonally high water table (fig. 2). The relationship was curvilinear for both species, with depths to gray mottles of less than 60 cm having proportionally more impact on growth than depths greater than 60 cm. The regression equations accounted for 60 percent of the variation in heights of slash pine and 79 percent of the variation in heights of iobioiiy.

There was also a strong positive relationship between depth to gray mottles and phosphorus concentration in needles. Coefficients of determination (R^2's) for the quadratic equations for these relationships were 0.65 for slash and 0.60 for lobioily pine. Apparently, the trees' abilities to extract phosphorus from the soil were influenced by the volume of soil their roots could exploit.

Of the several phosphorus determinations made on the soil, none were significantly correlated to height for both species (table 3). The combination of phosphorus intensity and 0.03*N* NH_4F + 0.1*N* HCl extract was significant for both species. However, the coefficient for the 0.03*N* NH_4F + 0.1*N* HCl in the equation predicting lobloily pine height was negative making meaningful interpretations difficult. After the quadratic relationship between height and depth to gray mottles has been fit, organic phosphorus and 1*N* NaOH extractable phosphorus also add significant contributions for loblolly pine, but their coefficients are negative. Again, at levels indicating a deficiency of

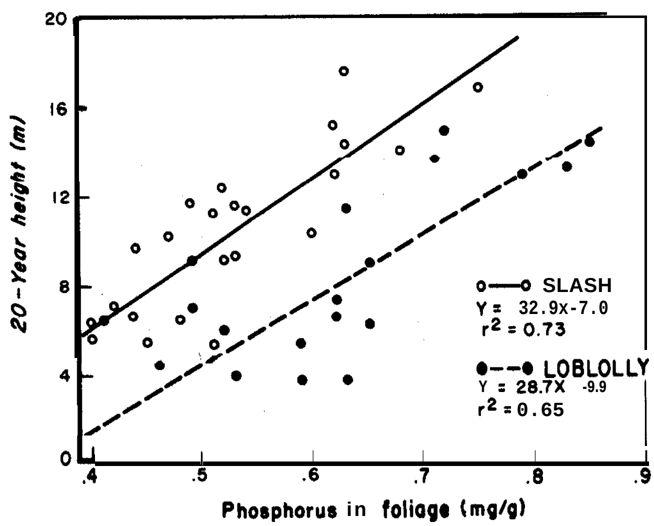

Figure 1.—*Relationship between phosphorus in foliage and height at age 20. Slopes of lines are not* ***significantly*** *different at 0.05 level but intercepts are.*

Table 3. — *Coefficients of determination between height at age 20 and various soil phosphorus rests*

Soil phosphorus test	Range	Slash	Loblolly
		------------- R^2	-------------
Organic phosphorus	13.2-36.5 μg/g	0.01	0.11
0.2*N* H_2SO_4	0.8-8.5 μg/g	0.01	0.07
0.03*N* NH_4F + 0.1*N* HCl	0.43-2.13 μg/g	0.25*	0.18
1*N* NaOH	2.7-34.9 μg/g	0.01	0.29"
Phosphorus intensity	0.27-1.75 μg/ml	0.06	0.27"
Phosphorus equilibrium concentration	.....	0.05	0.07
Phosphorus intensity; 1*N* NaOH	.....	0.08	0.47*
Phosphorus intensity; 0.03*N* NH_4F + 0.1*N* HCl	.....	0.27'	0.45'
Phosphorus equilibrium concentration; depth to gray mottles (quadratic)	.....	0.83'	0.88*

*Regression significant at the 0.05 level.

phosphorus, an equation predicting greater growth as the phosphorus measured in the soil decreases is not biologically meaningful.

The phosphorus equilibrium concentration accounted for only 5 and 7 percent of the total variation in slash and loblolly pine heights, respectively. However, the phosphorus equilibrium concentration accounted for 15 and 43 percent of variation in height of the two species remaining after fitting the quadratic relationship between height and depth to gray mottles. For loblolly, the R^2 increased from 0.79 to 0.88.

DISCUSSION AND CONCLUSIONS

In relatively small geographical areas of uniform climate, 20-year heights of slash and loblolly pines on phosphorus deficient soils can be predicted with confidence from the depth to gray mottles. This depth can also be used to predict phosphorus concentration in the needles but with more unexplained variation. The depth to gray mottles and height to age 20 measurements are by their nature integrated over time. The phosphorus concentrations were measured only once so the phosphorus measurements may not be as reliable.

The detrimental effect of a winter water table near the surface on growth of pines relates to its impact on root development. Boggie (1977) found that lodgepole pine (*Pinus contorta*) rooting depth was controlled by the depth to a water table in the winter months. Evidently prolonged saturation of the soil is fatal to the larger roots and the soil volume explored by repeated annual root growth is limited. In Louisiana, the surface area of fine roots of loblolly did not follow seasonal trends but was related to the winter water table (Lorio et al. 1972).

None of the phosphorus soil tests by themselves proved to be useful in predicting the growth of the two pine species. The uptake of phosphorus from these phosphorus deficient soils Is controlled by the volume of soil available for root exploration. The range in the amount of phosphorus available per unit volume of soil is small so the concentration of soil phosphorus has little effect. Lea et al. (1980) found soil tests failed to predict phosphorus content of the foliage of loblolly pine when the soil test values were low. They also suspected factors other than nutrient availability in the topsoil were involved.

The improvement in prediction equations obtained by fitting phosphorus equilibrium concentrations after depth to gray mottles probably occurs because the phosphorus equilibrium concentration is an estimate of the amount of added inorganic phosphorus that will remain in solution. In these phosphorus deficient soils, the main sources of plant available phosphorus are organic matter decomposition,

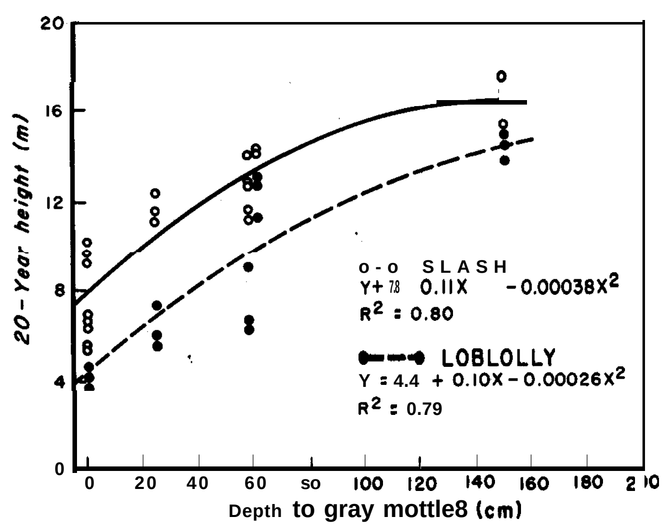

Figure 2.— *Effect of depth to gray mottles (winter water table) on height at 20 years of dominant and codominant slash and loblolly pines.*

throughfail, and atmospheric fallout. The phosphorus equilibrium concentration is a measure of the availability of phosphorus from these sources. As would be expected, relationship of phosphorus equilibrium concentrations to growth were stronger with the more phosphorus demanding iobioiiy pine than with the less phosphorus demanding slash.

Because the warm season rainfall exceeds 99 cm in southern Mississippi, slash pine is expected to be taller than iobioliy, if other factors are equal (Shoulders and Tiarks 1980). Figure 1 shows that slash pine is taller . than iobioiiy at a given concentration of phosphorus in the needles. Figure 2 indicates that slash pine is taller than iobioiiy when the., water table is at or near the surface. Unfortunately, the effects of climate, phosphorus nutrition, and rooting depth cannot be separated with the data available. White and Pritchett (1970) reported no interaction between fertilization, species, and control of the water table. in their study, **fertilization** increased the height growth of slash and iobioiiy pine equally. Water table control and a combination of fertilization and drainage also had no effect on the height difference between shash and iobioiiy pine.

Phosphorus fertilization is needed for maximum growth of iobioiiiy and slash pines on ail soils included in the study. Drainage, by bedding or other techniques, is also indicated for soils having seasonally high water tables (gray mottles) within about 60 cm of the surface. Levels of other nutrients, especially nitrogen and calcium, in these soils are low throughout the profile (Smith **1975),** and may become limiting for growth if excess water is drained from the sites and phosphorus fertilizer is applied. The need for additional nutrients cannot be determined, however, until the more limiting factors of excess water and inadequate available phosphorus have been removed.

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