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Soil properties relating to height growth of loblolly pine on four major soil series in East Texas

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SOIL PROPERTIES RELATING TO HEIGHT GROWTH OF LOBLOLLY PINE ON FOUR MAJOR SOIL SERIES IN EAST TEXAS [1]

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Abstract. Stem analysis was used to obtain age and height data for loblolly pine (*Pinus taeda* L.) stands growing on Bowie, Fuquay, Sacul, and Troup soils in northeastern Texas. The soil profiles were described and bulk soil samples were taken in each sample stand. Selected physical and chemical soil properties were measured for each soil horizon. Stepwise regression analysis was used to correlate average stand height at ages 5, 10, 20, and 30 years with soil properties. Strong associations were found between stand height and properties which relate to available soil moisture holding capacity, soil permeability, and soil aeration. For Bowie, Fuquay, and Troup soils, average stand height increased with increasing moisture holding capacity of the surface soil and with increasing subsoil permeability and aeration. On Sacul soils, height increased with better permeability and aeration of the solum. Average annual height growth on the four soils differed significantly only in the first 5 years, peaked between ages five and 10, and then declined. Average cumulative stand heights differed significantly between series until age 10. Differences in attained height at age 25 seemed more related to rapid early growth than to differences in later growth rates.

Introduction

Site index for loblolly pine (*Pinus taeda* L.) has been found to increase with increasing thickness of the A horizon (Coile 1952, Coile and Schumacher 1953) or depth to the least permeable horizon (Gaiser 1950), especially in shallow soils. This relationship, however, seems to be curvilinear (Ralston and Barnes 1955). As depth of surface soil increases, its effect on growth decreases and may become negative (Zahner 1958). In one study, 18 inches of surface soil seemed optimum for pine growth (Zahner 1957, 1958). Greater thicknesses were apparently not used, and surface soil below 18 inches seemed to function as a subsoil.

The Sacul, Fuquay, and Troup soil series all have an average site index of 80 for loblolly pine at age 50, while the Bowie series averages 83 (Dolezel 1975). These soils are all Udults, having formed under similar warm, moist climatic conditions from Coastal Plain sediments. They are all old, highly-weathered soils with low base saturation and have some degree of clay accumulation in the subsoil.

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Sacul soils consist of 5 to 15 inches of fine sandy loam over a clayey subsoil (USDA 1976a). They have a perched water table during part of the year. Bowie soils are similar to Sacul soils in having relatively shallow surface soils, 9 to 20 inches of fine sandy loam, but different in having a sandy clay loam rather than clayey subsoil (USDA 1976b). A fragipan may be present in Bowie soils.

Fuquay soils have a surface layer of from 20 to 40 inches of loamy fine sand (USDA 1969a). The subsoil extends to a depth of 80 to over 100 inches and consists of fine, sandy loam overlaying sandy clay loam. The Fuquay series has plinthite in its subsoil. The Troup series is distinguished by an extremely thick (> 40 inches) loamy, fine sand A horizon (USDA 1969a).

Considering the demonstrated importance of surface soil thickness, the variation present in Bowie, Fuquay, Sacul, and Troup soils would be expected to cause significant differences in site quality. The lack of such differences stimulates speculation. Is surface depth not a determining factor of site index, but rather only coincidentally correlated with a true determining factor which has not been measured? Do compensating factors exist in these soils? Are there differences in rate of height growth at younger ages that are no longer apparent at later ages?

This study was conducted, therefore, in order to examine the relationship of surface soil thickness to site index in Bowie, Fuquay, Sacul, and Troup soils and to see whether limiting soil factors change with stand age.

Methods

Study Area

The study area included roughly the northern half of the pineywoods of east Texas. This forested area has a humid climate, with hot summers and mild winters. Precipitation totals average 40-46 inches annually, and precipitation is fairly well distributed throughout the year (USDC 1969).

Data Collection And Analysis

Ten stands were sampled on Bowie soils, eleven on Fuquay, twelve on Sacul, and six on Troup soils. Samples were taken in stands of loblolly pine which were at least 30 years of age and which did not show evidence of suppression, high grading, or other bias-causing agencies. One plot, varying in size so as to include four dominant trees on a uniform soil, was located in each stand.

Increment cores were taken from each sample tree at breast height (4% ft) and at each 10-ft height interval starting at 10 ft from the ground and going to the top of the tree. Some samples were taken at logging operations and others by climbing the trees. Total height was measured either with a tape or by using a clinometer.

After the annual rings were counted, the adjustment recommended by Lenhart (1974) was used to approximate the apex of annual height growth for tree ages at each sampling interval. Age-height relationships were plotted for each of the four sample trees within each stand and a curve was fitted through the points. For each stand, the average tree height at 5-year age intervals was read from the curve and used in subsequent statistical analysis.

At each plot, a soil profile description was made and a bulk soil sample was taken from each soil horizon. The soil samples were analyzed to determine texture, organic matter, pH, soluble salt, calcium, magnesium, potassium, sodium, and phosphorus. Percent moisture retention was measured by extraction at field capacity (0.33 bars) and permanent wilting point (15 bars) (Richards 1947, 1954; USDA 1972). Available water capacity was approximated from soil texture data (Broadfoot and Burke 1958).

Statistical Analysis

For each soil series, the range of stand heights (from stem analysis data) at ages 5, 10, 20, and 30 years were examined separately. The data were also pooled and analyzed as a group. Based on scatter diagrams and correlation analysis, soil variables which seemed unrelated to stand height for specific soil/age combinations were deleted from further testing. For each soil and age combination, stepwise regression analysis techniques were used to derive regression equations for predicting average stand height based on measured soil properties. Statistical significance were determined at the 5-percent level unless stated otherwise.

Results And Discussion

Age-height Relationships

A comparison of cumulative stand heights on the four soil series showed that significant ($p < 0.05$) differences between soils existed only at ages **5** and 10 years. At these ages, stands growing on the Bowie soils had the greatest average heights, while stands on Sacul soils were the shortest on the average. Stands growing on Fuquay and Troup soils were intermediate. Height differences between stands on Fuquay and Troup soils were not statistically significant.

After age 10, differences in average stand height on the four soils were not significant. On the average, however, total stand height was greatest at all ages on Bowie soils and least on Sacul soils (Fig. 1). Stand heights on Troup and Fuquay soils were intermediate and had nearly identical average cumulative heights with less than a foot of difference in height at every age. It appeared that differences in stand height were established at a young age on these four soils and that the relative height ranking was still maintained at age 30.

In addition to total height, average annual height increment by 5-year intervals was also compared. This showed a significant ($p < 0.05$) difference in growth between all four soils during the first 5 years. Stands growing on the Bowie soils had the greatest average annual height increment and those on Sacul soils had the least (Fig. 1). Fuquay and Troup were intermediate, with stands on Fuquay soils having faster growth than those on the Troup soils.

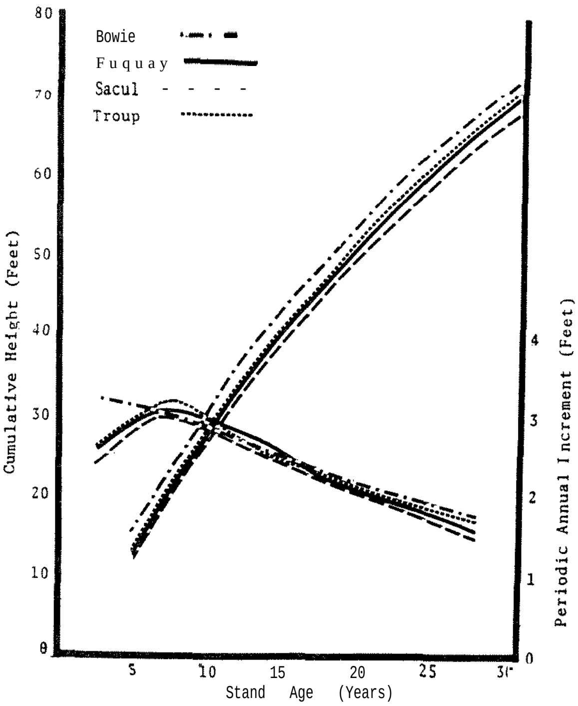

Figure 1. Average cumulative height and periodic annual increment for stands growing on Bowie, F'uquay, Sacul, and Troup soils.

There was no significant difference in stand growth on the four soils between the ages of 5 and 30 years. On all four soils, the greatest average annual height growth occurred by the age of 10 and the rate of growth declined steadily after that.

The data suggest that good sites established differences in height early in the life of the stand and that much of the difference in site index may be expressed by age 5 or 10 years. It is not possible to conclude from the data that soil is the sole determining factor, however. Differences in early growth might be due to soil factors, competition, or a combination of the two.

<u>Bowie Soils</u>

The regression to predict stand height at age 5 on Bowie soils was highly significant ($p < 0.01$), and significant ($p < 0.05$) regressions were obtained for stand height at ages 10, 20, and 30 years. The percent of variation accounted for by the regressions was 84, 80, 78, and 72 percent, respectively. Table 1 presents a summary of soil factors used to predict stand heights. The equations to predict stand height at age 5, 10, 20, and 30 years on Bowie soils are:

$$HT5 = 47.128 + 1.720X_1 - 0.481X_2 - 0.33513,$$
with $R^2 = 0.8447$, *

$Sy.x = 1.1107$, ** and

where HTn = stand height in feet at that stand age, and
X_n = variables identified in the accompanying table for the soil series;

$$HT10 = 24.245 + 1.578X_1 - 1.460X_4 - 0.343X_2$$
with $R^2 = 0.7997$ and $Sy.x = 2.0276$

$$HT20 = 27.119 + 1.131X_6 + 1.080X_7 - 3.617X_8$$
with $R^2 = 0.7815$ and $Sy.x = 3.7652$

* $R^2 \times 100$ = percent of height variation accounted for by the regression

** $Sy.x$ = standard error of the estimate

$$HT30 = 41.765 + 1.447X_6 + 1.197X_7 - 4.826X_8$$
with $R^2 = 0.7164$ and $Sy.x = 5.0615$.

Table 1. Soil factors used to predict stand height at ages 5, 10, 20, and 30 on Bowie soils.

Variable	Soil factor	Relation to height at stand age: 5	10	20	30
X_1	Water holding capacity of A horizon (inches)	+	+		
X_2	Weighted average percent silt-plus-clay of B horizon, not including B1	-	-		
X_3	Weighted average percent fine-plus-very fine sand of A + B horizons	-			
X_4	Weighted average percent sand of B horizon/thickness in inches of A horizon		+		
X_6	Depth to C horizon (inches)			+	+
X_7	Clay of surface soil (percent)			+	+
X_8	Water-holding capacity of the A-plus-B horizons (inches)				

Overall, it seems that high water-holding capacity of the surface soil favors early height growth on Bowie soils. A higher percentage of clay in the surface soil also favors growth, probably by increasing water holding capacity . The surface of Bowie soils consists of 9-20 inches of fine sandy loam or loamy fine sand, and Bowie soils are dry for 75-90 days in most years (USDA 1976a). It seems then that good seedling survival and growth depends on plentiful moisture in the surface soil, which is the primary zone of rooting. Even at later ages, small roots tend to be most concentrated in the upper soil and adequate surface soil moisture would promote growth.

On the other hand, the subsoil averages one-tenth or less of the permeability of the surface soil in the Bowie series (USDA 1976b). Excess moisture and poor aeration seem to be a problem, since a sandier subsoil favors growth. Greater water holding capacity of the entire solum (which is determined more by the thick B horizon than by the relatively thin A horizon) is associated with poor growth. The fact that greater subsoil moisture capacity seemingly favors growth at age 10 but is unfavorable at ages 20 and 30 might be attributable to early response to an increased moisture supply but then later growth inhibition because of the restricted effective rooting zone in the saturated subsoil.

Fuquay Soils

The regressions for stand height at ages 5, 10, and 30 were highly significant ($p < 0.01$), and the regression for height at age 20 was significant ($p < 0.05$). The regressions accounted for 85, 73, 84, and 92 percent of the variation in stand height at ages 5, 10, 20, and 30, respectively. The soil factors used to predict stand height are presented in Table 2.

Table 2. Soil factors used to predict stand height at ages 5, 10, 20, and 30 on Fuquay soils.

Variable	Soil factor	Relation to height at stand age:			
		5	10	20	30
X_9	Weighted average percent silt-plus-clay of A-plus-B1 horizons	+			
X_{10}	Weighted average percent silt of B horizon, not including B1				
X_{11}	Weighted average percent sand in A-plus-B horizons				
X_2	Weighted average percent silt-plus-clay of B horizon, not including B1				
X_{12}	Slope (percent)			+	+
X_{13}	Thickness of B horizon (inches)			+	+
X_3	Weighted average percent fine-plus-very fine sand of A-plus-B horizons			–	–
X_4	Weighted average percent sand of B horizon/thickness (inches) of A horizon			–	–

The equations to predict stand height based on properties of Fuquay soils are:

$$HT5 = 7.419 + 0.347X_9 - 0.192X_{10},$$
with $R^2 = 0.8453$ and $Sy.x = 0.6687$

$$HT10 = 72.366 - 0.491X_{11} - 0.273X_2,$$
with $R^2 = 0.7285$ and $Sy.x = 0.6606$

$$HT20 = 63.330 + 1.783X_{12} + 0.256X_{13} - 0.383X_3 - 3.692X_4$$
with $R^2 = 0.8395$ and $Sy.x = 2.3020$

$$HT30 = 83.999 + 0.441X_{13} + 2.179X_{12} - 0.548X_3 - 5.164X_4$$
with $R^2 = 0.9231$ and $Sy.x = 2.1291$.

Fuquay soils have a well-drained A horizon consisting of 20-40 inches of sand or loamy sand (USDA 1969a), and height growth of loblolly pine was favored by the increase in available water supply associated with a higher content of fine material in the surface soil.

At the same time, growth was improved by factors which act to reduce water-logging and prevent perched water tables in the subsoil. Fuquay soils have a sandy clay or sandy clay loam subsoil with moderate permeability in the upper B horizon and slow permeability below (USDA 1969a). During wet periods, there is commonly a perched water table above the plinthic zone which begins at a depth of 45-60 inches. Height growth improved with greater sand content of the subsoil, which improves downward percolation of water, and with a slight degree of slope, which allows lateral water movement.

Sacul Soils

It was not possible to derive a significant regression relating stand height at age 5 years to measured soil factors on the Sacul soils. Significant ($p < 0.05$) regressions were obtained for stand height at ages 10, 20, and 30, however. These regressions accounted for 68, 53, and 33 percent of the variation in stand height, respectively. The soil factors used to predict stand height on Sacul soils are summarized in Table 3. The equations derived from these factors are:

$$HT10 = 33.007 - 0.429X_{14} - 0.526X_1 + 0.007X_{15}$$
with $R^2 = 0.6776$ and $Sy.x = 2.3096$

$$HT20 = 51.761 = 0.395X_{14} + 0.218X_{10}$$
with R2 = 0.5341 and $Sy.x = 3.9880$

$$HT30 = 58.126 + 0.381X_{16}$$
with $R^2 = 0.3343$ and $Sy.x = 4.9188$.

Moisture-related properties seemed to be the key to productivity in the Sacul soils. The surface of Sacul soils consists of about 12 inches of fine sandy loam, sandy loam, or loam (USDA 1976a). The B2 horizon consists of silty clay or clay' and has a clay content of from 35-50 percent. The lower B2 horizon and B3 horizon are silty clay loam, clay loam, sandy clay loam, or silt loam. The A-plus-B ranges from 40 to 72 inches thick. The permeability of the B2 horizon to water movement is about one-tenth that of the A horizon. There is more available soil water in the B2 than the A horizon but most of it occurs in the B24 and B3 horizons, which are somewhat coarser-textured than the B2. There are few if any pores of larger than capillary size in Sacul subsoils, and near-saturation of the soil occurs above the water table.

Table 3. Soil factors used to predict stand height at ages 5, 10, 20, and 30 on Sacul soils.

Variable	Soil factor	Relation to height at stand age: 5	10	20	30
X_{14}	Depth to mottling (inches)				
X_1	Water-holding capacity of A horizon (inches)		-		
X_{15}	Subsoil moisture retention (percent m.r. at 0.33 bar- percent m.r. at 15 bars) X (horizon thickness in inches) summed for all B horizons		+		
X_{10}	Weighted average percent silt of B horizon, not including B1			+	
X_{16}	Weighted average percent silt of A-plus-B1 horizons				t

It would appear that good aeration is more important than high moisture holding capacity in the surface of Sacul soils. Stand height at age 10 is negatively correlated with available water holding capacity of the A horizon but height is positively correlated with moisture holding capacity of the subsoil. Since the surface soil is fairly shallow in Sacul soils, even a seedling would be able to draw on subsoil moisture reserves after the surface soil moisture is exhausted. On the other hand, poor aeration in waterlogged surface soil would cause heavy mortality of the small feeder roots which are concentrated in the upper soil.

In view of this, it was unexpected to find that height was negatively correlated with depth to mottling at ages 10 and 20. Mottling indicates that the soil is subject to alternate wetting and drying and that the horizon is saturated during part of the year. Generally, greater depth to mottling has been found to be related to higher site index, especially on poorly drained soils (Coile 1952). Since the reverse was true on these Sacul soils, it may indicate that the B horizon is saturated (and thus, recharged) with water during the dormant season but not during the growing season when poor soil aeration would be most harmful to tree roots.

Stand height at age 20 was favored by increasing silt content of the subsoil. Increasing subsoil silt in the range encountered in the samples (5-34 percent) brings the soil texture closer to a loam or silt loam. Although total water holding capacity is greater on heavier-textured soils, loam and silt loam soils have greater plant-available water holding capacities than soils of other textures (Buckman and Brady 1969).

Height at age 30 increased with increasing silt content of the surface soil in the range of 9-35 percent. Increasing silt content in this range would increase available water without causing poor aeration.

Troup Soils

Several samples which had been taken as Troup soils were found upon later examination to have non-typical profiles. Those samples, which had Troup profiles developing over older Rus ton soils, were dropped from the analysis. Few 30-year-old stands of loblolly pine were encountered on Troup soils, and it was not possible to replace the deleted samples. The small number of remaining samples makes it difficult to assign meaningful significance values to the regressions.

It was not possible to derive a statistically significant regression relating soil factors to stand height at age 5 years on the Troup soil. Highly significant ($p < 0.01$) regressions were obtained for ages 10, 20, and 30, however. These regressions accounted for 96, 97, and over 99 percent of the variation in stand height, respectively. The soil factors used in these regressions are presented in Table 4. The equations to predict stand height on Troup soils are:

$$HT10 = -1.274 + 0.597X_{17} + 12.703X_4$$
with $R^2 = 0.9600$ and $Sy.x = 1.1295$

$$HT20 = 55.805 + 0.713X_{17} - 3.118X_{10}$$
with $R^2 = 0.9692$ and $Sy.x = 1.0877$

$$HT30 = 53.839 + 1.031X_{17} - 6.492X_{10} + 2.436X_8$$
with $R^2 = 0.9998$ and $Sy.x = 0.1393$.

At ages 10, 20, and 30, stand height increased with increasing organic matter content of the A horizon. Troup soils have 40-72 inches of sand or loamy sand overlaying a sandy loam or sandy clay subsoil which extends to a depth of from 80 to over 120 inches (USDA 1969b). Organic matter would thus favor growth by increasing the water-holding capacity of these deep, coarse-textured soils as well as providing nutrients.

Average stand height at age 30 increased with increasing water-holding capacity of the solum. This is logical and could be expected for sandy, droughty soils such as these.

Simple linear regression showed stand height to increase with increasing silt content of the subsoil and also with decreasing subsoil sand content (larger values of the texture-depth index). However, these stand height-soil relationships were reversed when the soil variables were fixed in the regression equations, so that the fine material content of the subsoil would seem to be negatively related to growth. This seems unreasonable, considering the relatively small amount of fine material present in these deep coarse-textured Troup soils. The role of subsoil silt in Troup soils is unclear and its inclusion in the height prediction equations may be due to chance variation in the small sample.

Table 4. Soil factors used to predict stand height at ages 5, 10, 20, and 30 on Troup soils.

Variable	Soil factor	Relation to height at stand age: 5	10	20	30
X_{17}	Percent organic matter X inches horizon thickness, summed for all A horizons		+	+	+
X_4	Weighted average percent sand of B horizon/thickness (inches) of A horizon		+		
X_{10}	Weighted average percent silt of B horizon, not including B1				
X_8	Water-holding capacity of A-and-B horizons (inches)				+

Combined Data - All Soils

It was possible to derive significant ($p < 0.05$) regressions using pooled data for Bowie, Fuquay, Sacul, and Troup soils. As might be expected, however, the regressions were much weaker than those for the individual soils. Since none of the regressions using combined data accounted for more than 29 percent of the variation in stand height, they will not be presented in this paper.

Conclusions

Strong associations were found between stand height and soil properties, particularly those which relate to available soil moisture- holding capacity, soil permeability, and soil aeration. Both surface soil and subsoil properties were important, and the growth-limiting factors seemed to vary with stand age.

The thickness of the A horizon was not clearly related to height growth of loblolly pine during the first 30 years after stand establishment on Bowie, Fuquay, Sacul, and Troup soils. Rather, the most important properties of the surface soil were related to its available moisture-holding capacity. Stand height increased on Bowie, Fuquay, and Troup soils with increasing water holding capacity of the surface soil. In contrast, on the finer-textured Sacul soils, permeability and aeration seemed to be a limiting factor even in the surface soil and stand height was negatively related to water holding capacity of the surface soil.

The thickness of the soil layer, which is favorable for root growth, did seem to be related to height growth. A readily permeable, well-aerated subsoil was necessary for good growth of loblolly pine on all four of the soil series. The soils which lacked these qualities had a shallow effective rooting depth which inhibited development of a deep, extensive root system and they were associated with slow-growing stands of loblolly pine.

The soil factors which controlled growth of loblolly pine stands on these four soils varied with stand age. In general, surface soil characteristics were most important for young stands. The root systems of young trees must be in contact with sufficient soil water to supply the needs of the plants during the dry summer months. In the Bowie, Fuquay, and Troup soils, this moisture was obtained when the surface horizons had a high water-holding capacity. Stands growing on Sacul soils seemed to be favored by a well aerated A horizon overlying a moist subsoil which was within reach of the root systems of the young trees.

At later ages, when the root systems more completely occupied the soil, the characteristics of the subsoil became more important. In all four soils, a permeable, well aerated subsoil apparently enabled the establishment of a deep, widespread, healthy root system and was associated with the best growth of loblolly pine.

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