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Relationship of Shortleaf Pine Growth to Soil Properties

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INTRODUCTION

Appraisal of land's productive capacity for timber is difficult, especially when trees of the desired species are not present. Accumulating evidence indicates that measurements of physical soil factors may be used to predict potentialities of a site for tree growth, in regions where soil differences are the major cause of variation in site quality.

An intensive study of the growth of shortleaf pine plantations in relation to differences in soil properties was made in a small area of Missouri in 1952. This research proved important as it added weight to results of similar investigations elsewhere. The principal result was the discovery that site quality for shortleaf pine was strongly related to thickness of the surface horizon and the percentage of clay this layer contained. Site quality, as measured by height growth, was much better on soils with deep *A* horizons rich in clay than on those with shallow *A* horizons containing little clay.

DESCRIPTION OF STUDY AREA

Plantations were available for study in the Ashland Wildlife Research Area in Boone County, near the center of the state. They were located on old fields, on or near ridge tops, which generally have cappings of loess. The loess in places lay directly on limestone bedrock; elsewhere weathered drift of the Kansas ice sheet lay between the loess and bedrock.

The soils in this region were classified by Kellogg (1938) in the gray-brown podzolic soil group. Most of the plantations were located on Weldon soil, a series described by Scrivner and Frieze (1951) as a pale brown soil with a yellow-brown, plastic, silty-clay subsoil; it is low in agricultural productivity. One plantation was located on Lindley loam, a light-colored soil with a sticky, yellow-brown gritty clay-loam subsoil. This soil is derived from glacial till and has low fertility. Another plantation was located on a site where the soil body had been scraped away a few years before plantation establishment, leaving heavy parent material of weathered glacial drift exposed.

Because of agricultural cultivation and erosion, soil profiles in the study area were not typical of profiles under natural forest, especially in the surface layers (Fig. 1). Erosion had removed the upper layers in varying amounts, and cultivation had disturbed the soil, so that the typical forest-soil *A* horizon was not present.

Figure 1. Profile of Weldon soil on one of the plots. The zone from 15 to 18 inches is the gray layer which marked the bottom of the *A* horizon. Black iron and manganese concretions typical of this soil are visible.

COLLECTION AND ANALYSIS OF DATA

Data were collected from seven plantations ranging in age from 12 to 16 years. Because of variation in survival within a plantation and between plantations, stand density was not uniform. In general, however, the stands were moderately well stocked. Diameter growth being greatly affected by density of stocking, the best available index of site quality for these young stands was average annual height growth during the life of the trees. Preliminary study showed that growth varied from about 1 to 2 feet per year, indicating marked variation in site quality over the study area, presumably due in part to soil differences.

Twenty-eight plots, each about 20 feet square, were established and the average annual growth of trees in height was computed. A pit was dug at the plot center. The soil profile was described to a depth of 2 feet. Composite soil samples for mechanical analysis and other laboratory tests were collected separately from the soil horizons down to 24 inches below the surface. Constant-volume samples of the upper 3 inches were taken for measurement of permanent wilting percentage and field capacity. The vertical distribution of fine roots (smaller than 3 millimeters in diameter) on the pit face was recorded.

Mechanical analyses were made in the laboratory by the hydrometer method. Plasticity number, the difference between lower and upper plastic limits, was determined by a method adapted from Casagrande (1932). Soil color was determined by use of Munsell charts and instructions supplied by Pendleton and Nickerson (1951). Organic matter content was determined by a wet combustion method described by Peech *et al.* (1947). Hydrogen-ion concentration was measured with the Beckman pH meter. Permanent wilting percentage was obtained by growing sunflower seedlings in containers of soil in field condition. The difference between moisture content at field capacity and at wilting was used as an expression of the amount of moisture available to the trees at field capacity. Hydroscopic moisture was computed as the loss in weight from air-dry to oven-dry condition, expressed as a percentage of oven-dry weight.

Data indicated that a multiple linear regression was the means of statistical analysis best suited to show relationship of the several soil factors to height growth. Accordingly, the data were subjected to this treatment. Statistical significance (5-percent level) of regressions and correlation coefficients thus obtained were computed by methods described by Snedecor (1946).

Lutz and Chandler (1946) divided soil characteristics into two classes: (1) relatively permanent, and (2) temporary (subject to appreciable change during relatively short periods of time). Measurements of permanent factors are more likely to be reliable for predicting site quality than are measurements of temporary characteristics. Temporary properties sometimes are changed by plants during a short period of years. Consequently, permanent and temporary soil properties were treated separately in the analysis.

RELATIONSHIP OF PERMANENT SOIL PROPERTIES TO SITE QUALITY

Four characteristics of the *A* horizon—thickness, percentage of clay, plasticity number, and hygroscopic moisture—together were associated with 74 percent of the variation in mean annual height growth. The first two properties, thickness and percentage of clay, are more readily determinable than the others. A combination of these two factors resulted in a statistically significant regression, explaining 72 percent of the variation in site quality. The regression equation follows:

Mean annual height growth = 1.05 + .0192 (thickness of *A* horizon) + .0157 (percentage of clay in *A* horizon).

The standard error of estimate for this equation is 0.14 foot; therefore, in the study area it is possible by means of the regression equation to predict, two times out of three, the average yearly height growth within 0.14 foot.

A tabular presentation of predicted mean annual height growth, based on the equation, is presented in the accompanying Table 1.

Figure 2. Interior view of plantation on the scraped area, *A* horizon missing. These trees, planted in the spring of 1942, have averaged only 1 foot per year in height growth.

RELATIONSHIP OF MEAN ANNUAL HEIGHT GROWTH TO THICKNESS OF THE A HORIZON AND PERCENTAGE OF CLAY IN THE A HORIZON

Percentage of Clay in A horizon	Thickness of A Horizon in Inches										
	0	2	4	6	8	10	12	14	16	18	20
	Mean Annual Height Growth in Feet										
0	1.05	1.09	1.13	1.17	1.20	1.24	1.28	1.32	1.36	1.40	1.43
5		1.17	1.21	1.25	1.28	1.32	1.36	1.40	1.44	1.48	1.51
10		1.25	1.29	1.33	1.36	1.40	1.44	1.48	1.52	1.56	1.59
15		1.33	1.37	1.41	1.44	1.48	1.52	1.56	1.60	1.64	1.67
20		1.40	1.44	1.48	1.51	1.55	1.59	1.63	1.67	1.71	1.74
25		1.48	1.52	1.56	1.59	1.63	1.67	1.71	1.75	1.79	1.82
30		1.56	1.60	1.64	1.67	1.71	1.75	1.79	1.83	1.87	1.90
35		1.65	1.68	1.72	1.75	1.79	1.83	1.87	1.91	1.95	1.98

Among the 28 plots, thickness of *A* horizon varied from 0 to 20 inches; percentage of clay in the *A* horizon averaged 21, ranging from 0 to 34. Fig. 2 shows a plot where there was no *A* horizon. The predicted average growth (1.05 feet) is close to actual growth (1.15 feet). Another plot is pictured in Fig. 3. The *A* horizon here was 4 inches thick and had 22 percent clay. Predicted growth was 1.48 feet per year, actual 1.51.

Regressions of height growth on plasticity number and hygroscopic moisture individually were statistically significant; however, addition of

Figure 3. Plantation on Weldon soil, average annual height growth 1.5 feet, age 12 years.

these independent variables to the regression based on thickness and percentage of clay showed that they did not contribute significantly to a prediction of site quality. Their failure to strengthen site-quality prediction may be due to the fact that they are highly correlated with clay content.

Percentage of silt-plus-clay in the *A* horizon also was correlated to a marked degree with site quality. However, as an expression of the capacity of the soil for tree growth, it was inferior to percentage of clay.

Thickness of *A* horizon (or depth to a tight subsoil) is of general importance as a gauge of site quality. The findings of other investigators also bear out its general importance in affecting tree growth (Auten, 1937, 1945; Turner, 1938; Roberts, 1939; Minckler, 1943; Coile, 1948; Gaiser, 1950; Gessel and Lloyd, 1950; Goggans and May, 1950; Goggans, 1951).

The importance of percentage of clay in the *A* horizon is supported by research on pine growth in Arkansas, where site quality increased with increase in clay content in the *A* horizon (Turner, 1938). According to Baver (1948), the clay fraction of the soil is the most active textural class with respect to availability of soil moisture and soil nutrients. Consequently, in soils with small or moderate amounts of clay, site quality is likely to be related directly to clay content. However, soils with high clay content might show inverse relationship of clay percentage to site quality because of unfavorable physical properties associated with large amounts of clay. This inverse relationship appeared in studies of tree growth on heavy soil by Hayes and Stoeckeler (1935) and Harper (1940).

Two subsoil characteristics, percentage of clay and plasticity number of the *B* horizon, were combined with thickness and percentage of clay of the *A* horizon in regression analysis. The results indicated that these two subsoil properties do not add significantly to the prediction of site quality based on the previously given equation. Inability to show association of subsoil differences with height growth variation may be due to the fact that the plantations are young. As the trees grow older, root competition will increase. The lower soil layers will become relatively more important than they are now.

RELATIONSHIP OF TEMPORARY SOIL PROPERTIES TO SITE QUALITY

Organic matter and pH of the *A* horizon were inversely related to site quality—sites with high organic matter and high pH were poorest. Organic matter content and pH were relatively low, averaging 0.95 percent and 4.80, respectively. Increases in organic matter and pH would be expected to improve site quality. However, in the plantations studied, it is likely that differences in organic matter content and pH of surface soil are *results* rather than *causes* of differences in tree growth. On good sites, where plantations had developed rapidly, the ground was well covered with pine needles, which tend to increase soil acidity. Organic matter incorporation into mineral soil is slow under pine needle litter. On poor sites, where trees grew slowly, the ground was covered with herbs (mostly grasses), under which organic matter was incorporated into mineral soil. Thus, good sites have rapidly growing pine trees with acid mineral soil low in organic matter; poor sites have slow-growing pine, abundant herbaceous ground cover, less acid mineral soil, and higher organic matter content.

Available moisture in the upper 3 inches (field capacity minus wilting percentage) was not correlated significantly with site quality. This soil property ranged from 14 to 24 percent, averaging 20 percent.

The range of color in the soils studied was slight; no consistent relationship of soil color to site quality could be established.

ROOT DISTRIBUTION AND SOIL PROPERTIES

The number of fine roots in a cross-section of the *A* horizon 2 feet wide averaged 172, varying from 59 to 335. Site quality was directly related to the number of fine roots in the *A* horizon. Further analysis showed that the number of fine roots was dependent upon thickness of this horizon. For each 1 inch increase in thickness, the number of roots increased nine.

Although site quality was related to percentage of clay in the *A* horizon, the number of fine roots in this horizon apparently was not related to this particular soil property or to the other properties studied.

The number of fine roots in a 2-foot cross-section of the *B* horizon (down to 24 inches below the surface) averaged only 13. Apparently this number was related to only one soil property of those studied—thickness of *A* horizon. An increase of 1 inch in thickness of this horizon resulted in a decrease of two in number of fine roots in the *B* horizon.

SUMMARY AND CONCLUSIONS

An intensive study of soil conditions related to the growth of 12- to 16-year-old planted shortleaf pine was conducted in 1952 at the Ashland Wildlife Research Area in Boone County. Soils of the study area were largely silt loams derived from loess. Twenty-eight plots were established in seven plantations. Average annual growth in height was determined at each plot and used as a measure of site quality. Samples of soil from the *A* and *B* horizons were taken separately for measurement of soil properties. Distribution of roots in the soil profile was recorded.

The main results of the study were:

1. Seventy-two percent of the site quality variation was associated with differences in (1) thickness of *A* horizon, and (2) percentage of clay in the *A* horizon.

2. A formula was derived which shows the relationship between rate of height growth and *A* horizon thickness and clay percentage. A table showing these relationships was developed using this formula.

3. The preceding combination of soil properties was the best, of all those examined in this study, for prediction of pine site quality.

4. Differences in subsoil characteristics were not related to site-quality variation.

5. The best sites had the lowest organic matter and pH in their *A* horizons, probably because rapid pine plantation growth promoted soil acidity and decreased incorporation of organic matter into mineral soil.

6. The numbers of fine roots in the *A* horizon and in the *B* horizon were related to thickness of *A* horizon. Apparently no other soil property of those studied appreciably affected the number of fine roots.

These results constitute further evidence of the importance of certain soil properties to tree growth. They demonstrate that it is possible to predict site quality, in some cases, upon the basis of a few, relatively simple soil measurements.

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