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SITE PRODUCTIVITY OF OAKS IN RELATION TO SOIL PROPERTIES AND TOPOGRAPHY IN NORTHERN ILLINOIS

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ABSTRACT

Cubic foot volume yields of black oak, white oak and red oak were correlated with soil properties of the A_1 and subsurface horizons plus topographical variables of 62 plots. Yield predicting equations based upon soil properties of the A_1 or subsurface horizons and topographical variables were computed by multiple regression. The best equations were obtained when based on subsurface horizons. A combination of variables from the A_1 and subsurface horizons gave the highest correlation, explaining 66 percent of the variation in yield. A yield predicting equation based on soil properties easily identified and quantified in the field that accounts for 42 percent of the variation in yield is given for forest management purposes.

The most widely accepted method of forest site evaluation in the United States is the direct estimation of forest yield from suitable trees. However, the limited range for extrapolation of site evaluation from this method severely curtails its usefulness. Relating yield to relatively stable environmental features such as soil and topography provides an alternative basis for forest site evaluation. This method is applicable where suitable forest trees are not present and can also be used in other locations having similar soils, topography, and climate.

Generally, soil and/or topographic factors that influence moisture supply have been shown to be most important in forest site evaluation. These factors include soil texture, stone content, soil depth, depth to mottling, water-holding capacity of the soil, slope gradient, physiographic position, aspect and the concavity or convexity of the slope. For example, McClurkin (15) found percent clay of the B horizon, depth to the least permeable layer, and 15-bar water retention

of the least permeable horizon to be the determining factors of site quality for oaks in western Tennessee and northern Mississippi. Carmean (4) concluded that soil depth, texture, stone content, and drainage the most important soil characters influencing growth of upland oaks in the central United States. Other investigators have reported similar findings (5, 10, 19).

The chemical content of the soil has also been used to predict productiveness of forest soils (8, 9, 11) but to a lesser extent than those factors related to available soil moisture. Individual cations, organic matter, percent base saturation, phosphorus, and nitrogen content of the soil have been used for this purpose (17, 20, 21).

One of the first steps necessary for intensive forest management is to determine the site quality of an area. With this information for each unit of land, forest managers can better determine which tree species or combination of species will most nearly meet the desired objective. This paper reports the relationship between the physical and chemical soil properties and topography to growth of black oak (*Quercus velutina* Lam.), white oak (*Q. alba* L.) and red oak (*Q. rubra* Michx.) in northern Illinois.

MATERIALS AND METHODS

The study was conducted in the Sinnissippi Forest in northwestern Illinois. The area is primarily an oak-hickory forest in the westernmost part of the eastern deciduous forest. Black oak and white oak usually in mixed stands predominate on the uplands sites while red oak is usually found mixed with white oak on the better sites.

The surficial geological deposits of the area consist of sand dunes, outwash, valley trains, alluvial deposits, loess, sandstone and limestone bedrock. Till is not extensive in the area but occurs as surficial deposits in isolated spots usually overburdened by loess.

In 1948 several hundred circular 1/5 acre plots were established in the Sinnissippi Forest for research purposes and to also aid in managing the forest. One hundred and ten of these plots were used in the present study. Only plots that were well stocked, at least during one of the three time spans covered by the four inventories conducted between 1949 and 1971, were considered. Further screening was based on species composition, age of the stand (91 to 110 age class) and soil characteristics.

Most of the field work for the study was conducted during the summers of 1971 through 1974. Soil uniformity, slope percent, and distance from center of the plot to the ridge of the slope was determined. Soil samples from major horizons of eleven soil series from 62 plots were taken to a depth of 60 inches or to a shallower depth coinciding with solum thickness. The soils included eight Hapludalfs, one Quartzipsamment, one Udipsamment, and one Hapludoll, ranging in texture from fine-silt to very fine sandy.

Soil samples were air dried, crushed and screened through a 2 mm sieve. Particle size distribution was determined by a simplified pipette method as described by Follmer (6). Available soil water for 36 representative soil samples were determined by difference between water held at 1/3 and 15 bars as described by Richards (18). Since there is a close relationship between soil texture and available soil moisture (12, 16), available water for the remaining soil samples were obtained by interpretation from soil texture.

Nitrogen was determined by a modified Kjeldahl method as described by Bremmer (3). Cation exchange capacity (CEC) was determined by saturating the soil with ammonium using neutral normal ammonium acetate. Exchangeable Ca and Mg were determined on the ammonium acetate leachate obtained from the CEC determination by atomic adsorption and Na and K on the acetate leachate by flame ionization. Percent base saturation (% BS) was determined by determining the proportion of the cation exchange capacity occupied by the exchangeable bases extracted by ammonium acetate. Available P (P_1 and P_2 tests) were determined by methods described by Bray and Kurtz[1] (2). Soil pH was determined with a glass electrode on a 1:1 soil:water suspension.

Tree and mensurational data that included forest type, site quality, tree height, species, age, diameter at breast height (d.b.h.) and disposition (fate of previously measured trees) were collected in four inventories in 1949, 1954, 1963, and 1972. Total heights of sample trees were used to develop equations to obtain wood volumes for each forest type, age class, and site quality by the least squares method as described by Gevorkiantz and Olsen (7).

Growth expressed in cubic feet per acre per year was used as a measure of soil productivity. Although volume growth is more difficult to obtain than height growth it is preferred for hardwoods because it is more sensitive to environmental conditions. Furthermore, when some hardwood trees reaches a certain age, they may continue to increase in volume while their heights may remain constant (14).

Separate weighted averages were obtained for soil parameters of the A_1 horizon and the rest of the profile. This procedure was necessary since several samples were taken at various depths in each profile selected for sampling. If more than one sample was taken for a given horizon, an average weight of its value for each horizon was obtained according to the thickness of the soil layer in which it occurred.

Stepwise regression analysis was used to determine the contribution of each soil variable to yield. Equations were developed from 44 variables of the surface horizon and topographic variables, the subsurface horizons and topography, and a combination of the two soil horizons with topography.

RESULTS AND DISCUSSIONS

Simple Regression Correlations

Results of simple correlations between yield and selected soil and topographic variables showed that variables of the subsurface horizons

were better correlated with yield than with topographic or soil variables of the A_1 horizon. Yield was also better correlated with soil physical properties of both the A_1 horizon and subsurface horizons than with soil chemical properties of these horizons. Furthermore, logarithmic transformations of the soil variables were better correlated with yield than were nontransformed values.

Percent silt, available soil water, and their log transformations were better correlated with yield than any other soil variable, suggesting that water is the most limiting factor for tree growth in the study area. Other soil variables of the A_1 horizon significantly correlated with yield are N, percent clay and exchangeable Ca, and K. Significant correlations were also found between yield and CEC, and exchangeable Ca, Mg, and K of the subsurface horizon.

Multiple Regression Analysis

Exchangeable Na, percent very fine sand, and pH were not included in these regression analyses because Na was used in the computation of percent base saturation, sand was used in the calculation of available water and pH was used only as an informative variable as it was nearly uniform throughout the study plots.

A_1 Horizon:

A predicting equation calculated from topographic and soil variables of the A_1 horizon showed that log of available water, log of slope, log thickness of A_1 horizon, Ca, Mg, percent base saturation, P_2 test, P_1 test and K to be the significant variables. These variables explained 51 percent of the variation in yield.

Log of available water was the most potent variable in the equation explaining 25 percent of the variation. Slope and thickness of the A_1 horizon were significant in the equation even though both variables were weakly correlated with yield in the simple correlation analyses. The fact that thickness of the A_1 horizon appears in the equation is more than likely the result of the mechanics of the regression technique and probably no real relationship exist between this variable and yield for the majority of the soils. Ten of the eleven soil series in the study had similar ranges in thickness of the A_1 horizon, although the soils differed widely in productivity.

When topographic variables were removed from the equation, log percent silt, percent base saturation, log Mg, CEC and Mg were the most potent variables explaining 44 percent of the variation in yield.

Subsurface Horizons:

The yield-predicting value of soil variables from the subsurface horizons together with the topographic variables were tested by stepwise regression. Eleven variables were retained in the equation which explained 63 percent of the variation in yield. The log of available water was the most potent variable, followed by slope, log reciprocal of percent base saturation, log thickness of subsurface, P_2, K, log K, log percent sand, percent silt, log Ca and log N. Analyses of variance for subsurface horizons show that soil variables of this horizon in conjunction with

topography are superior to the surface variables for predicting yields. This superiority is attributed in part to the fact that erosion has removed part of the surface soil.

Surface and Subsurface Horizons:

Selected variables were screened by the stepwise regression technique to obtain a yield-predicting equation that included most variables. The best equation (with R^2 of .66) relating tree growth to soil and topographic variables was

$$\text{Yield} = -164.66 + 18.49 \log (\%\ \text{silt subsurface}) + .25 (\%\ \text{Clay } A_1) + 11.19 \log \text{slope} + .22 (\%\ \text{BS } A_1) + .42 (\text{K subsurface}) - 34.74 \log (\text{N subsurface}) + 51.93 \log (1/\%\text{BS subsurface}) - 32.35 \log (P_1\ A_1) + 28.84 \log (P_2\ A_1) + 102.32 \log (\%\text{BS subsurface}) - .45 (\%\text{BS subsurface}) - .31 (\text{Mg } A_1)$$

Distance from ridge has often been reported correlated with tree growth but this variable does not appear in the equation because all soil types studied except one, are underlain by permeable materials. This results in water percolating through the profile having a larger vertical vector component than a horizontal one. The net results are that percolating waters are out of reach of most tree roots. The other topographic variable (slope) was found positively correlated with yield in the equation. An increasing slope gradient would enhance the importance of the horizontal vectors component of water movement with the net result that soil water is more within reach of tree roots.

Logarithm of percent silt accounts for the highest variation in yield. In the soils of this study percent silt is highly correlated with percent available water in both the A_1 horizon and subsurface horizons. Inferences made about percent silt can also be made about available water. The relatively high percentage of silt in most of the soils, including some of the sandy soils, can be attributed to a substantial loess component in their parent material.

The nutrient status of the soils generally showed good correlations with yield except for P. Simple correlations between P of the A_1 horizon and yield were .13 and .19 for P_1 and P_2 tests respectively but were about .32 for Ca, N and K. The soil tests for P were developed and calibrated for agricultural crops and their use to assess the availability for certain tree species have limitations. Our results compare favorably with Alban (1) who obtained poor prediction values by the Bray and Kurtz (2) methods for P extraction, when comparing ten methods of extracting soil P for the purpose of site index prediction of red pine in Minnesota. However, the low correlations between yield and soil P tests can be partly attributed to the fact that P levels appear to be adequate for the growth of the oaks in our study.

The nutrient status of the soil, as measured in this study, is to some extent a limiting factor to tree growth. Exchangeable K in subsurface horizons has the highest correlation with yield of all the

nutrients and K deficiencies are most likely to occur in sandy soils of low CEC (13). If available soil moisture becomes a nonlimiting factor to tree growth in the study area, K probably would be the first nutrient to become limiting.

Exchangeable Mg was significantly correlated with yield but is believed to be nonlimiting to tree growth in the study area. Mg deficiences can occur due to imbalance of this element with Ca and K, but no such unfavorable ratios were observed in the soils of the study. Soil N was also correlated with tree growth but high correlations between this variable and other variables better correlated with yield preclude any definite conclusion.

In general, the nutrients seem to be correlated with tree growth, but soil physical conditions appear to be more limiting over the study area.

Prediction Of Yield For Management Purposes By Soil Features Easily Recognized In The Field

Yield prediction for forest management purposes using the best equation discussed above would be time consuming and expensive to obtain. Therefore, selected soil features easily recognized in the field were used to compute a yield-predicting equation which is given below:

$$\text{Yield} = 55.28 + 18.06 \log (\%\ \text{silt subsurface}) + .13\ (\%\ \text{clay}\ A_1) + 1.00\ (\text{thickness subsurface}) - 65.91 \log (\text{thickness subsurface})$$

This equation is less precise than the other equations in the study as indicated by the R^2 of .42. However, the small number of variables in this equation coupled with the ease in obtaining these values may justify its use for management purposes. In the above equation, silt content of the subsurface horizon is the most potent variable in the equation followed by clay of A_1 and thickness of subsurface. Percent silt of the A_1 horizon did not enter in the equation because of the strong correlation existing between it and the percent silt in the subsurface horizons. Percent silt of the subsurface horizons is a good estimator of potential available soil water in these soils. This variable in conjunction with thickness of the subsurface horizon can be a useful tool for yield prediction.

Percent clay of the A_1 horizon is a good estimator of some of the nutrient level of the soils studied. This fact is indicated by the high correlation between % clay and exchangeable Ca, Mg, and K (R^2 of .74, .72, and .61 respectively). A small increase in the R^2 would probably be obtained by substituting any of these nutrient elements for clay in the equation as they are better correlated with yield than clay. But these variables are costly to obtain and cannot be easily estimated in the field.

This yield-predicting equation is not applicable to other tree species and it should not be extrapolated very far outside the range of soil

characteristics and/or environmental conditions present in the area in which the study was conducted.

SUMMARY

An equation of soil and topographic variables was made with tree growth of the A_1 and subsurface horizons. Forty-four percent of the variation in yield could be accounted for by soil properties of the A_1 horizon with an additional seven percent by topographic variables. Percent silt in the A_1 horizon was the most potent variable in the equation. Other variables of this horizon correlated with yield were potential available water, percent slope, P_1, P_2, thickness of A_1 horizon, % BS, exchangeable Mg and exchangeable K.

Variables of the subsurface horizons were better predictors for yield than variables of the A_1 horizon. The subsurface soil variables with topographic variables accounted for 63 percent of the variation in yield. Potential available water, percent slope, % BS, thickness of subsurface horizons, P_2, exchangeable K, percent sand, percent silt, exchangeable Ca and total N of the subsurface horizons were correlated with yield.

Selected soil variables of the A_1 and subsurface horizons plus topographical variables explained 66 percent of the variation in yield. Log of percent silt of the subsurface horizons was the variable best correlated with yield accounting for 31 percent in the variation in yield. Other variables in this group correlated with yield were percent clay, % BS, exchangeable Mg, P_1 and P_2 of the A_1 horizons. In addition, exchangeable K, total N and % BS of the subsurface horizons plus percent slope were also correlated with yield.

An equation based on easily recognizable and quantifiable soil features was developed for forest management purposes. Percent silt of the subsurface horizons, percent clay of the A_1 horizon, thickness and log thickness of the subsurface horizons, in that order of importance, accounted for 42 percent of the variation in yield.

The most potent soil nutrients in the study were the exchangeable bases and total N. Potassium of the subsurface horizons was the nutrient best correlated with yield while Ca was the next best. Very low correlations were obtained between P_1 and P_2 phosphorus and yield.

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