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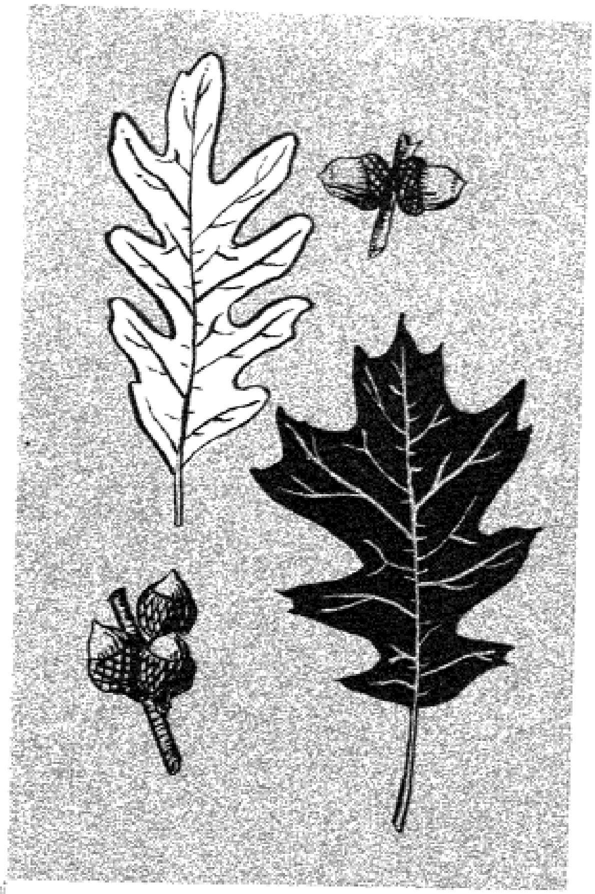
TOPOGRAPHY & SOIL RELATIONS for WHITE and BLACK OAK



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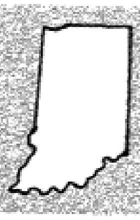

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Topography and Soil Relations for White and Black Oak in Southern Indiana[1]

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Numerous papers have been written on soil-site relations for upland oaks in various sections of the eastern deciduous forest (Carmean 1965, 1968; Della-Bianca and Olson 1961; Doolittle 1957; Einspahr and McComb 1951; Gaiser 1951; Gysel and Arend 1953; McClurkin 1963; McGahan *et al.* 1961; Schnur 1937; Trimble and Weitzman 1956). This paper describes the soil-site relations of white (*Quercus alba* L.) and black oaks (*Quercus velutina* Lam.) on unglaciated soils of the Norman and Crawford uplands in southern Indiana. These uplands occupy approximately 5,000 sq. miles (13,000 sq. km.) in 19 counties.

The gray-brown podzolic soils of the southern Indiana uplands are derived from sandstones and shales of Mississippian and Pennsylvanian age and varying amounts of wind-deposited silts (loess). Zanesville, Tilsit, Muskingum, and Wellston are the most important forest soils in the region, and all sample plots were established on these series. Some soils of limestone origin do occur in the uplands but were not included in the sample. Zanesville and Tilsit are common soil series on the loess-covered broad upland ridges and gentle slopes. These series usually have fragipan layers that occur between 26 and 42 inches below the surface; the soils are moderately well-drained to well-drained. The Muskingum and Wellston soil series, common on steeper slopes, represent a wide range of soil depth, stoniness, and texture, and are both classified as well-drained to excessively drained.

METHODS

Study plots were located only in fully stocked, undisturbed, even-aged stands of mixed oaks or mixed hardwoods. Of the 146 fifth-acre plots established, white oak was measured on 126 and black oak on 86. Stand ages ranged from 28 to 106 years, and site index, estimated from curves by Schnur (1937), ranged from 38 to 86 for white oak and 42 to 94 for black oak. Within each plot total height and total age (age at 4½ feet plus 2 years) were determined from at least four dominant and codominant free-growing trees of each species present.

In addition, the following information was obtained on each study plot: Soil profiles were described and soil types identified. The thickness of the A horizon (A1 + A2 horizons) was measured in 12 places. Composite soil samples were collected from the major soil horizons in four pits and analyzed for texture (Bouyoucos 1951) and stone content (percent by weight of material greater than 2 mm). Slope aspect, slope position, and slope steepness were the recorded topographic features.

Analysis of Data

Analytical procedures similar to those described by Carmean (1965) were used in this study. The objective was to relate site index to specific soil and topographic features ob-

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served on the plots. Study plot data for each species were analayzed by multiple regression using the model:

$$\text{Log total tree height} = b_0 + b_1 (1/\text{total age}) + b_2 X_2 + \cdots b_n X_n.$$

This equation describes the relation between total tree height and various coded transformations of tree age, soil, topography, and certain first-order interactions among these features.

First, scatter diagrams were made to observe trends of variables suspected of accounting for substantial variation in a soil-site relationship. Eleven promising variables were arranged in apparent descending order of importance, and R^2 values were computed for all combinations of 1 to 11 variable equations using a step-wise screening program developed by Furnival (1964). An equation containing variables significantly related to tree height was then selected for further refinement. The variables in this equation were fixed in the regression analysis and then additional variables were tested in groups of 11 to determine if they significantly improved the precision of the initial equation. Transformations and interactions tested were those found significant in the study by Carmean (1965) plus those suggested from field experience. Forty-nine transformations were tested for white oak and 27 for black oak.

All retained variables were then tested for significance by analysis of variance. Significant effects and interactions, plus three nonsignificant, but nonetheless important interactions were retained in the equations and coefficients were calculated.

RESULTS AND DISCUSSION

The Equations

The final equations for predicting site index of white and black oak are:

White oak (126 plots): $R^2 = 0.84$

$$\begin{aligned} Y = {} & 2.48209 - 12.42516/X_1 + 0.03026\,X_2 + 0.00110\,X_3 \\ & - 0.00114\,X_4 + 0.01751\,X_5 - 0.00383\,X_7 - 1.19984/X_7 \\ & - 0.00137\,X_8 - 3.19761/X_9 - 0.00082\,X_{10} - 0.00036\,X_{11} \\ & + 0.00010\,X_{12} - 0.00057\,X_{14} - 0.00010\,X_{15} - 0.00034\,X_{16} \\ & - 0.00097\,X_{17} \end{aligned}$$

Black Oak (86 plots): $R^2 = 0.85$

$$\begin{aligned} Y = {} & 2.68882 - 23.44295/X_1 - 0.00109\,X_1 + 0.03670\,X_2 \\ & - 0.18273/X_2 + 0.00126\,X_3 - 0.00524\,X_6 - 0.00076\,X_7 \\ & - 0.00108\,X_8 + 0.00035\,X_9 - 0.00056\,X_{11} - 0.00171\,X_{12} \\ & + 0.00050\,X_{13} - 0.00027\,X_{15} \end{aligned}$$

Where:

Y = Logarithm of total tree height (feet)

X_1 = Total tree age

X_2 = Surface soil (A1 + A2 horizons) thickness (inches)

X_3 = Percent distance to ridge = (distance to ridge/length slope) 100

X_4 = $[(\text{sine azimuth from southeast}) + 1]\ 100$

X_5 = Slope shape (convex = 1; linear = 2; concave = 3)

X_6 = Slope steepness (%)

X_7 = Clay content of B2 horizon (%)

X_8 = Clay content of B3, BX, or C horizons (%)

X_9 = Silt content of B1 horizon (%)

X_{10} = Sand content of A2 horizon (%)

X_{11} = Stone content of B2 horizon (%)

X_{12} = $[(500 - 10{,}000/X_1)\ (100 - X_6)]\ 1/100$

X_{13} = $[(500 - 10{,}000/X_1)\ (X_3)]\ 1/100$

X_{14} = $[(500 - 10{,}000/X_1)\ (X_9)]\ 1/100$

X_{15} = $(X_2)\ (X_3)$

X_{16} = $[(X_2)\ (300 - X_4)]\ 1/10$

X_{17} = $[(300 - X_4)\ (100 - X_7)]\ 1/100$

The standard errors for a single observation at the means of each of the variables are shown in Table 1. Precision of these estimates can be improved if several site observations are made at a particular field location.

Table 1. — Standard error of estimate, standard deviation, and coefficients of multiple determination for the most precise equations computed for white oak and black oak

Item	White oak	Black oak
Number of plots	126	86
Average site index (feet)	66.4	71.8
Average tree age, years	54.0	50.2
Average tree height (feet)	68.2	71.6
Standard deviation of tree heights (feet)	± 12.1	± 12.1
Standard error of estimate of mean tree height (percent)	± 8.16	± 7.99
Coefficients of multiple determination (R^2):		
a. For age, soil, and topographic transformations	.842	.847
b. For age and topographic transformations	.569	.544
c. For age transformations	.368	.336

Approximately 84 percent ($R^2 = 0.84$) of the observed variation in tree height was associated with variations in the factors finally included in the equations; only 37 percent of the variation in tree height for white oak and 34 percent for black oak is associated with variation in tree age.

The equations were used to calculate site prediction tables for field use in the unglaciated uplands of southern Indiana; these have been presented elsewhere (Hannah 1967).

Cause and effect relationships cannot be shown in a random sample lacking experimental controls. Nevertheless, the repeated occurrence of the same variables in this and other soil-site studies (e.g. Carmean 1965, 1968; Doolittle 1957; Einspahr and McComb 1951; Gaiser 1951) — variables that account for a significant amount of observed variation — is a strong indication that we are dealing with variables closely associated with the physical and chemical site requirements for tree growth. The following speculations as to the basic causes for the observed differences in site will be better understood with the help of Figures 1 and 2, which are based on the regression equations and show the relation between site index and the important soil and topographic features.[2]

Depth of Surface Soil

Analysis of preliminary equations indicated that depth of the surface soil (A1 plus A2 horizons) is the most important environmental feature measured. As depth of the surface soil increases, site index for white and black oak increases (Figs. 1A, 1B, 2A, 2D). This trend, over the range of observed conditions, is linear for white oak and slightly curvilinear for black oak, the latter indicating a decline in the rate of site index increase as surface soil becomes deeper. Thickness of the A horizon was an important factor in the Ohio soil-site study by Carmean (1965); and in a study by Doolittle (1957) the A horizon thickness accounted for 91 percent of the variation in site index for oak in the southern Appalachians.

Surface soils on undisturbed oak sites in southern Indiana are loose and porous and generally well aggregated, and contain substantial amounts of incorporated organic matter. Such soils are a desirable medium for root growth because they have favorable moisture and nutrient characteristics and are well aerated. Therefore, the deeper the A horizon, the greater the volume of soil available for better root and top growth.

Considerably more soil volume than contained in the A horizon is required to supply water and nutrient requirements for trees. In southern Indiana the soils with deep A horizons usually have deep subsoils with desirable physical properties for rapid tree growth. On sites with shallow A horizons the subsoil is generally shallow and frequently stony, or it is high in clay content with low aeration porosity; consequently tree growth is slower.

[2] *Site index was calculated by setting tree age equal to 50 years, fixing variables at their mean sample value, and varying the factor of interest in each relationship.*

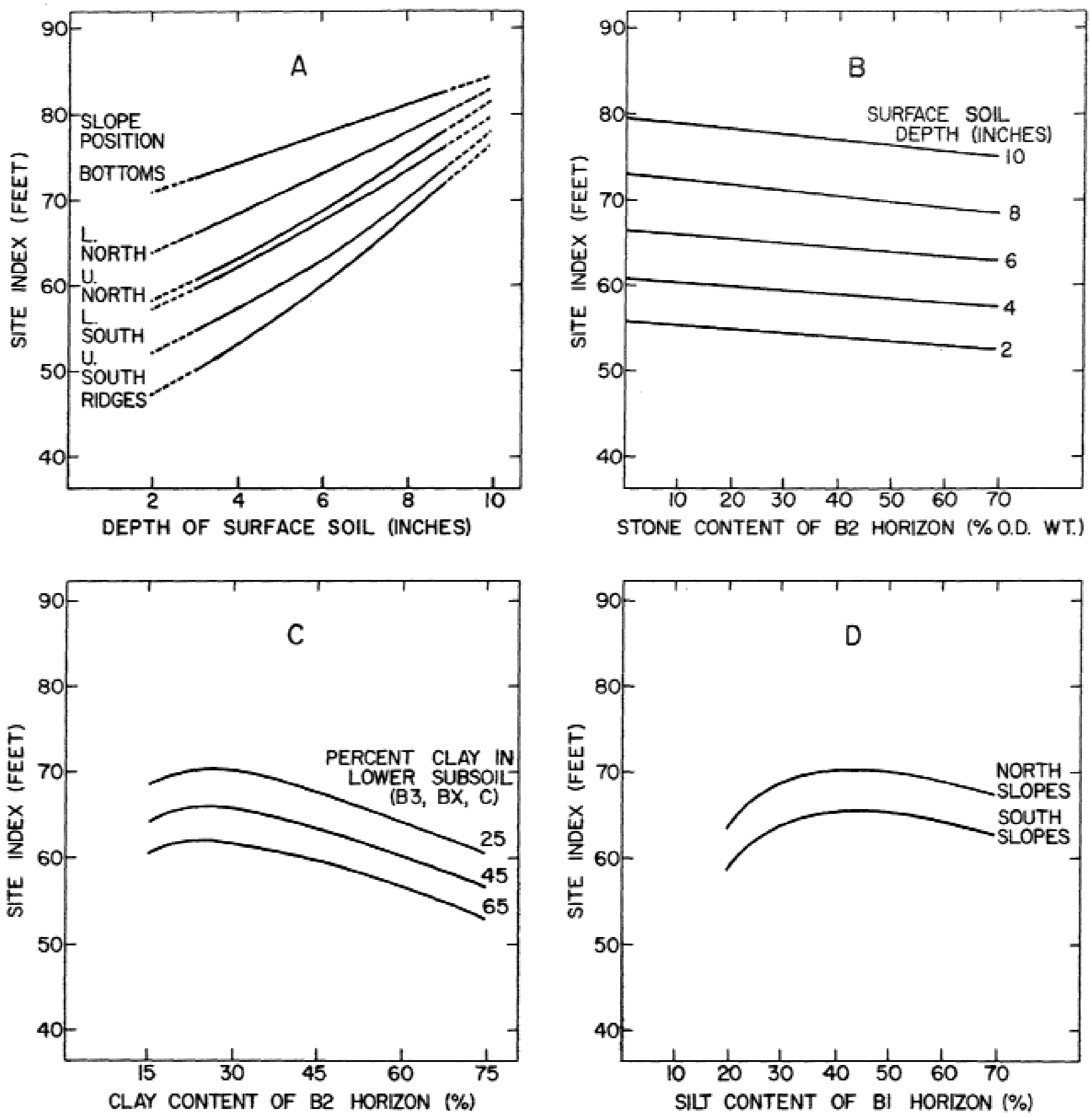

FIGURE 1. — Site index (feet — age 50 years) of white oak growing on Zanesville, Tilsit, Wellston, and Muskigum soils, as related to surface soil thickness (A1 + A2 horizons), slope position, stone content of B2 horizons, particle size fractions of subsoil horizons, and aspect.

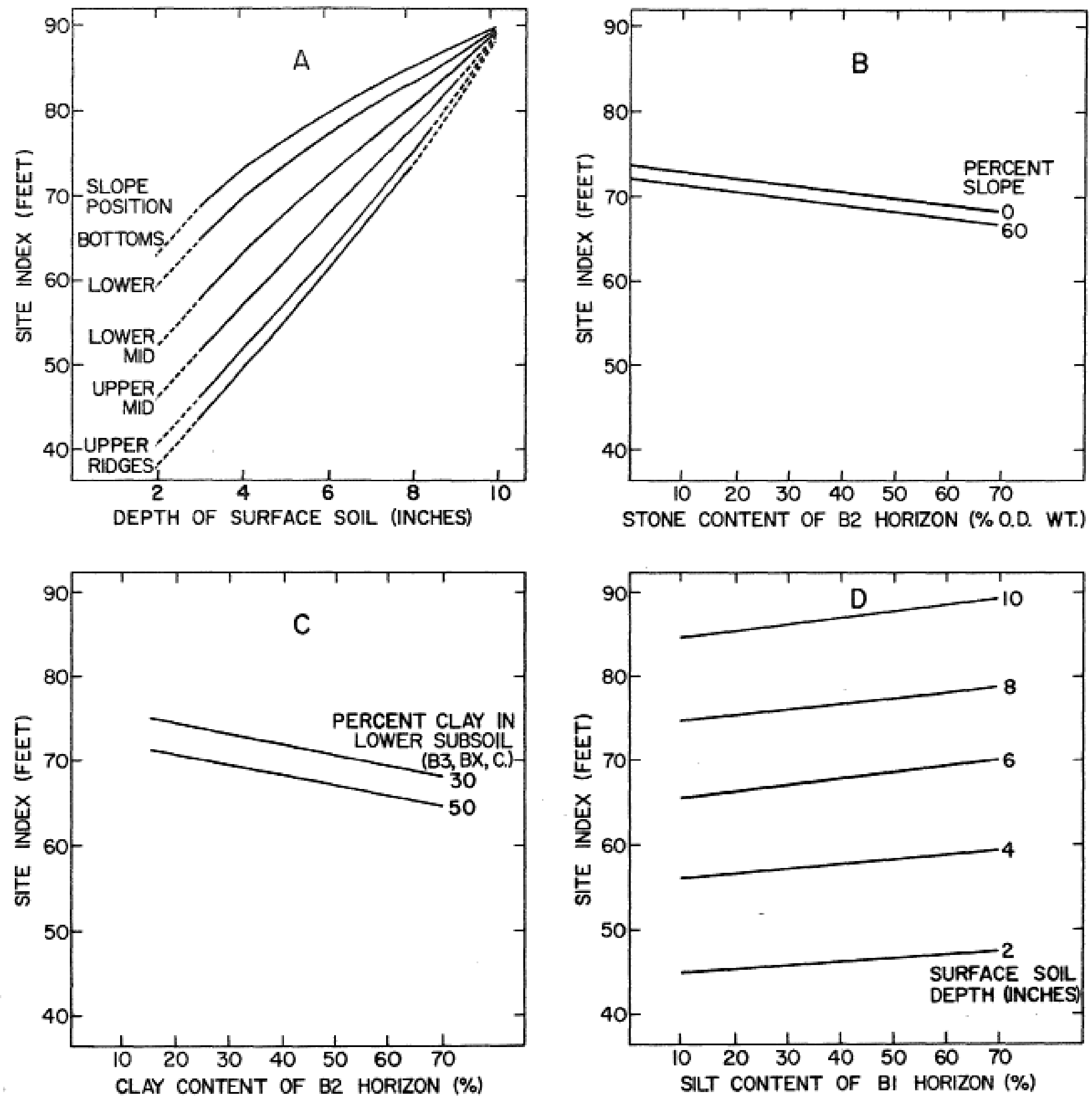

FIGURE 2. — Site index (feet — age 50 years) of black oak growing on Zanesville, Tilsit, Wellston, and Muskigum soils, as related to surface soil thickness (A1 + A2 horizons), slope position, stone content of B2 horizon, particle size fractions of subsoil horizons, and slope steepness.

Surface soil depth also is closely related to microclimate in the rough hilly country of southern Indiana. Deep A horizons occur on north-facing slopes, on lower slopes, and in coves where moisture and temperature are more favorable for tree growth. In contrast, thin A horizons generally occur on ridges and upper south-facing slopes where moisture is often limiting and temperatures are greater.

The good growth in areas of deep A horizons, then, is probably related both to favorable surface soil and subsoil properties and to favorable microclimate.

Clay Content In Subsoils

Site quality for white and black oak is best on sites with medium-textured subsoils (sandy clay loams, loams, and silt loams) and declines as soils become finer-textured (Figs. 1C and 2C). The site index trend for white oak is curvilinear, reaching a maximum at about 25 percent clay in the B2 horizon and then declining with increased clay content. Black oak shows a linear decrease in site quality as clay content in the B2 increased. Increasing clay content in the B3, BX (Fragipan), or C horizon results in a gradual decline in the site quality for both species (Figs. 1C, 2C).

These relationships suggest that soil moisture and soil aeration are near optimum for growth of white and black oak in the medium-textured subsoils. On sandier soil, aeration is good but less moisture is retained under the same precipitation pattern and so height growth of white oak is slower. On heavy-textured soils (clay loams, silty clay loams, silty clays, and clays), impeded aeration is apparently a detrimental factor and site quality for white and black oak gradually declines.

Silt Content of B1 Horizon

Site quality for black oak increases linearly as silt content of the B1 horizon increases (Fig. 2D). The trend for white oak is curvilinear, showing a sharp increase in site quality up to about 45 percent silt content and thereafter a gradual decline (Fig. 1D). These relationships suggest that with increasing silt content and proportionally less clay, improved aeration results in better growth of black oak. With white oak extremely high silt contents result in declining site quality, apparently because of reduced aeration in a uniformly fine, dense, and often poorly structured subsoil. These less favorable soil conditions for white oak usually occur in the thicker loess deposits of broad upland ridges.

Stone Content

Site quality for white and black oak decreases as stone content (material greater than 2 mm) of the subsoil increases (Figs. 1B, 2B). A similar trend was reported for black oak on medium-textured soils in Ohio (Carmean 1965). Probably the greater the volume of stone the less the volume of soil available for use by tree roots.

Slope Steepness, Position, and Aspect

Increasing slope steepness is not a significant factor in the site relations for white oak but results in a slight decrease in site quality for black oak (Fig. 2B). In southeastern Ohio, Carmean (1965) found that, for fine-textured soils located on broad, relatively flat ridges, site increased with increased slope steepness. He concluded that, under those conditions, an increase in slope steepness improved soil drainage and aeration and hence site quality. However, for medium-textured soils on steeper slopes Carmean (1968) obtained results similar to those of this study, namely, site decreases with increased slope steepness.

Site quality for both species improves with increasing distance from the ridge. This better growth is no doubt partially due to additions of gravitational water and to subsurface water flow from upper slope positions (Hewlett 1961) and to more favorable microclimatic conditions found on lower slopes.

White oak site quality in southern Indiana is decidedly better on north facing (NW, N, NE, E) slopes than on more southerly (SE, S, SW, W) aspects (Fig. 1D). However, aspect is not a significant factor in the site relations for black oak. The larger quantities of radiation received by south-facing slopes (Geiger 1965) undoubtedly result in greater evapotranspiration which creates more severe moisture stresses within trees than occurs on less exposed north-facing slopes. Site quality is lower on south slopes than on north slopes because, ultimately, less moisture is available for tree growth. Work by Finney *et al.* (1962) in Ohio suggests that soil development is less favorable for tree growth on south slopes than on north slopes; northeast slopes had deeper litter and A1 horizons and more desirable chemical conditions than southwest slopes. These soil relations are undoubtedly largely due to differences in microclimate and soil moisture regimes associated with aspect and also with corresponding differences in floral and faunal composition.

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