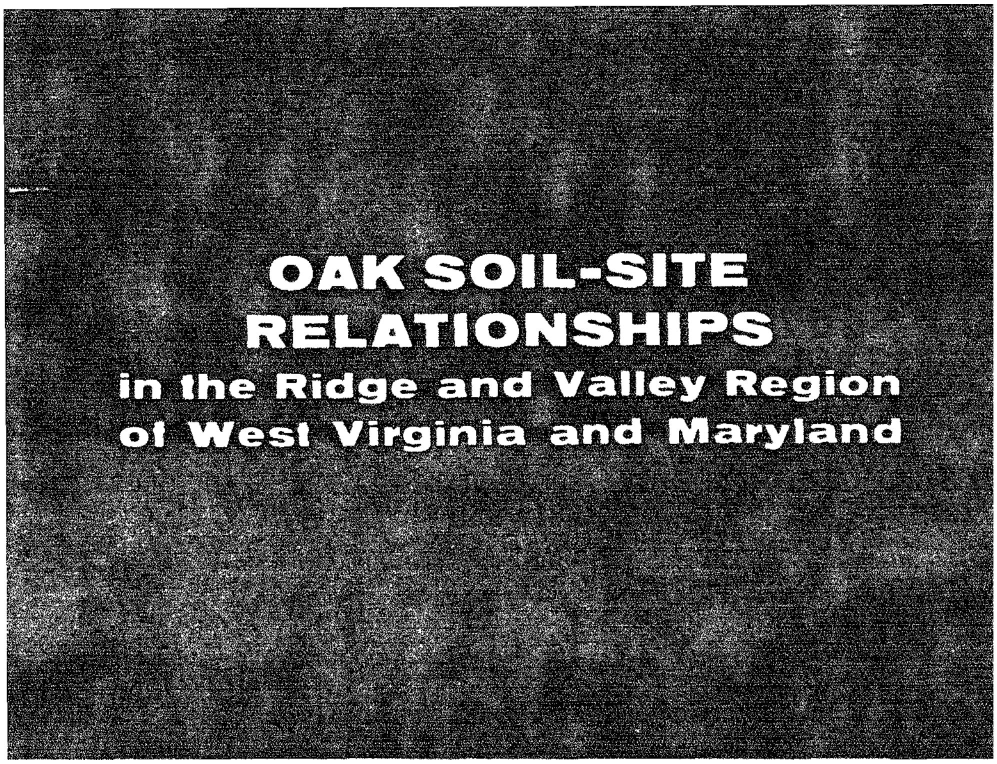

OAK SOIL-SITE RELATIONSHIPS in the Ridge and Valley Region of West Virginia and Maryland

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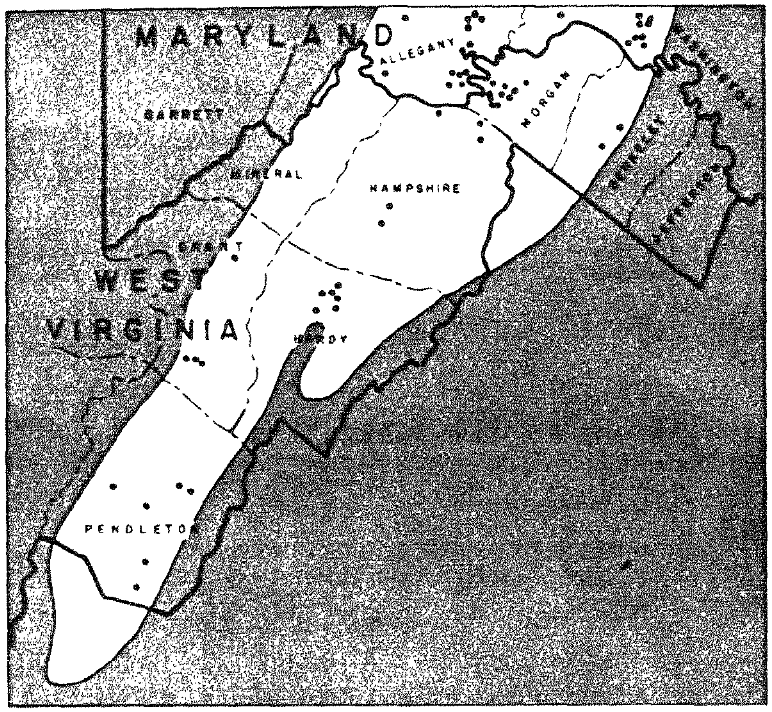
INTRODUCTION

A MAJOR FACTOR in the success of any forest-management program is the ability of the forester to evaluate forest areas and to delineate them into appropriate site-quality classes. It is mainly site quality that determines the growth potential of trees, and site also affects species composition and timber quality. For these reasons, a knowledge of site quality is basic in making decisions about management systems and stand-treatment priorities.

The most logical expression of site quality is a measure of the stand produced by the desired species on that site. However, for this measure to be reliable, the species must be present on the area in undisturbed stands that utilize the site completely. But too often these conditions are not met.

Many site studies made in the past 20 years have shown that, in the absence of suitable stands, site quality in terms of site index can be evaluated through the interpretation of soil-site factors found to be related with tree growth. This paper reports on such a soil site study made of five important oak species—red, scarlet, black, chestnut, and white oak — on upland sites in the Ridge and Valley Region of northeastern West Virginia and western Maryland (fig. 1).

Figure 1.—The portion of the Ridge and Valley Region covered by this study, and the location of the oak site plots.



PREVIOUS STUDIES

Soil-site studies made in various parts of the northern red oak range have established the importance of physiographic features and soil characteristics for predicting oak site quality.

The most pertinent of these for our study was made by Trimble and Weitzman (*1956*) in the Mountain area of West Virginia and Maryland to the west of the Ridge and Valley Region. They found that oak site index was closely related to aspect, position on the slope, slope percent, and depth of soil to bedrock. The northeastern slopes were between one and two 10-foot site-index classes higher than the southwestern slopes. Site index also improved with increasing distance from ridge top, decreasing slope percent, and increasing soil depth. In a re-analysis of the data, Trimble (*1964*) was able to show that soil depth could be eliminated from the prediction equation without appreciably affecting the multiple regression correlation coefficient or the accuracy of the estimated site index. The elimination of soil depth was possible because of the relationship of soil depth to slope position and slope percent.

In the Arkansas Ozarks, Arend and Julander (*1948*) showed that oak site indexes varied with the depth of the soil to unconsolidated parent material, slope position, and aspect. In addition, they found that productivity was influenced by the parent material: the best sites occurred on soils derived from calcareous materials, the poorest on soils developed from sandstone and shale. Yawney (*1964*) also showed that in West Virginia oak site quality generally was better on a limestone soil — Belmont silt loam — than on sandstone and shale soils of similar texture.

Einspahr and McComb (*1951*) demonstrated in northeastern Iowa that site index improved as the soil depth increased, as the texture changed from sand or loamy sand to silt loams of good structure, and as the aspect changed from southwest towards northeast. Slope percent was shown to be significant, but only on the southern and western aspects. In southeastern Ohio, Gaiser (*1951*) reported that site indexes of white oak were influenced by slope position, aspect, and thickness of the A horizon. Gysel and Arend (*1953*) concluded that oak yields in southern Michigan were related to subsoil texture, slope position, and steepness of the slope.

Doolittle (*1957*) found a strong relationship between the site index of scarlet and black oak and the depth of the A horizon. This single variable accounted for 91 percent of the variance in site index. The percent of sand in the A horizon and the slope position were also significant variables. Although aspect had a definite effect on site index when considered alone, it was not significant in the presence of the other variables because of correlations with them.

Carmean (*1961*), examining the relationship of soil type and site index of black oak in southeastern Ohio, found that, because of the extreme variability in site index, soil type alone could not be used to estimate sites accurately. He concluded that if soil taxonomic units are to be useful, either they must be refined or they must be subdivided into phases based on the specific soil and topographic factors that are closely related to forest site quality. The soil and topographic factors he found important for estimating site quality were depth of the surface soil, subsoil texture, subsoil stone content, aspect, slope position, and slope steepness.

Studying mixed oaks, yellow-poplar, and shortleaf pine on upland sites in the Virginia-Carolina Piedmont, Della-Bianca and Olson (*1961*) found that the major portion of the variance in tree height was accounted for by stand age. In contrast to numerous investigators elsewhere, they found only weak relationships with topographic and soil variables and concluded that this was due to the size of the geographic area and the large number of soil types included in their study. They further concluded that accepted techniques for identifying and measuring soil and other site factors may not be precise enough for the conditions encountered.

In addition to the site factors — slope position and the percent of clay in the surface horizon — McClurkin (*1963*) found it necessary to include basal area and stand age to arrive at a workable prediction equation for white oak in northern Mississippi and western Tennessee.

STUDY AREA

The topography of the Ridge and Valley Region is unique: a series of almost unbroken, long, parallel mountains oriented in a general northeast-southwest direction. The slopes are steep, rough and rocky, rising to an average elevation of 1,500 feet above the broad intervening valleys. Rock outcroppings are primarily sandstone or bands of shale, the latter being most common on the lower slopes. Limestone formations are found only in localized areas.

The sandstones and interbedded shales give rise to a variety of soil types and conditions. Soils on the ridge tops are generally shallow and coarse-textured, and they tend to be excessively drained. Textural composition and internal drainage are more favorable over a major part of the slopes, but towards the bottom, where the slopes become less steep, there is often a transition towards imperfectly drained soils. Here, in many places, fragipans have developed within the first 24 inches.

Precipitation over this part of the region averages about 35 inches annually and ranges from 30 inches in the south to 38 inches in the north. Based on 30 years of record, approximately 20 inches fall from April through September. Temperatures in this 6-month period average 66°F., and droughts of varying duration in midsummer and late summer are not uncommon. The frostfree growing season is about 160 days.

In the Ridge and Valley Region, the oaks are almost universally the dominant species on the upland sites. One or more oak species, either in pure stands or in mixture with other species, occur in all situations from the bottom of the slopes to the ridge top. On the main slopes and ridges, various oak types are represented by northern red oak (*Quercus rubra* L.), scarlet oak (*Q. coccinea* Muenchh.), black oak (*Q. velutina* Lam.), chestnut oak (*Q. prinus* L.), and white oak (*Q. alba* L.). Frequently pitch pine (*Pinus rigida* Mill.) and Virginia pine (*P. virginiana* Mill.) are strong components along with red maple (*Acer rubrum* L.), several hickories (*Carya sp.* Nutt), and black gum (*Nyssa sylvatica* Marsh). The species composition becomes more diverse on the lower slopes and in the shallow ravines with the integration of white pine (*Pinus strobus* L.) either as scattered individuals or in patches, yellow-poplar (*Liriodendron tulipifera* L.), basswood (*Tilia americana* L.), white ash (*Fraxinus americana* L.), and sugar maple (*Acer saccharum* Marsh.).

STUDY METHODS

In an effort to shortcut the work, we first attempted to use the oak site-index prediction equation developed by Trimble and Weitzman (*1956*) for the Mountain Province that borders our study area on the west. Site indexes estimated by their equation were compared with plot site indexes determined from tree measurements.

The rationale for this approach was the similarities of the soils sampled in both regions. Not only are texture, drainage, and parent materials similar, but the geologic series are the same. However, there are differences between the two regions in topographic configuration, elevation, and climate. We expected that an analysis of the Trimble and Weitzman equation would reveal one of three things, depending upon the magnitude and distribution of the differences between the two site-index values: (1) that the Trimble and Weitzman equation could be applied directly; (2) that this equation could be adjusted to cover the Ridge and Valley Region; or (3) that it would be necessary to develop a separate prediction equation for the Ridge and Valley Region.

The field procedures in this study followed the methods of Trimble and Weitzman (*1956*). The selection of the plots was restricted to upland even-aged oak stands occuring on medium-textured, well-drained soils derived from sandstone and shale parent material. Plot size was variable but, to minimize soil and topographic variation, did not exceed 1/5 acre.

The independent variables contained in the Trimble and Weitzman equation — aspect, slope position, percent slope, and soil depth — were carefully measured, and, following the appropriate transformation, estimated site index was calculated for each plot using their equation:

$$\text{Log site index} = 1.9702 - 0.0618X_1 + 0.0012X_2 - 0.0020X_3 - 0.1509X_4.$$

Measurement of each variable was made as follows:

Aspect (X_1). — Orientation of the slope measured with a hand compass facing down the slope and across the plot (transformed as the sine of the azimuth from southeast + 1).

Slope position (X_2). — Distance of the plot from the ridge expressed as a percent of the total slope length.

Percent slope (X_3). — Steepness of the slope over a distance of 2 chains across the plot and expressed as a percent.

Soil depth (X_4). — Average depth determined from observations made in a pit at the plot center, and from measurements made with a soil probe (*Yawney 1959*) 30 feet on either side and above and below the plot center. The soil pits were dug either to bedrock or to a depth of 4 feet. Where it was possible, the probe was used in the pits to record additional soil depths to a maximum of 6 feet. However, in the above equation 3.5 feet was the maximum soil depth used to predict site index (transformed as the reciprocal of soil depth).

As shown later in the analysis, the Trimble and Weitzman equation was tried in the Ridge and Valley Region on the basis of 30 plots. However, the study was later expanded to include a total of 57 plots. From the start, an effort was made to sample the full range of prevailing conditions. The number of plots in each site-class as well as their distribution by topography and soil depth is given in table 1.

The soils were described by soil scientists of the Soil Conservation Service, U. S. Department of Agriculture.[1] The most frequently sampled soils were either the channery or stony phases of the Laidig, Dekalb, Lehew, Calvin, and Mench series. Provisions for laboratory analysis of soil samples were not included in this study. Soil texture was determined by feel at the pit. A field colormetric kit was used to record reaction of the various horizons.

[1] The authors are indebted for the soils description work done by John L. Gorman and William Curry, soil scientists, Soil Conservation Service in West Virginia; and to Kenneth M. Stone, soil scientist, Soil Conservation Service in Maryland. Also, appreciation is expressed for the assistance provided by State County Foresters Leon Wilson of West Virginia and Harry M. Hartman of Maryland, in locating the study plots.

Table 1.—Distribution of the 57 study plots by site class, topography, and soil depth

(Number of plots)

Site-index class	Aspect			Slope position (distance from ridge over total slope length, in percent)				Slope steepness (percent)			Soil depth (feet)				Number of plots in each site class
	NE	SE & NW	SW	0-25	26-50	51-75	76-100	0-20	21-40	41+	1.5-2.4	2.5-3.4	3.5-4.4	4.5-6.0	
50 (45-54)	1	7	3	4	4	2	1	3	7	1	3	—	3	5	11
60 (55-64)	3	21	4	12	8	7	1	10	17	1	1	5	10	12	28
70 (65-74)	2	12	1	—	5	6	4	4	8	3	—	2	3	10	15
80 (75-84)	1	2	—	—	1	2	—	1	2	—	—	—	1	2	3
Totals	7	42	8	16	18	17	6	18	34	5	4	7	17	29	57

Five oak species, which occurred on the plots in varying proportions, were sampled in this study: red, scarlet, black, chestnut, and white oak. On each plot, tree heights and ages were taken on 5 to 10 dominants and co-dominants, and site indexes were determined by referring to the curves developed by Schnur (*1937*). Height measurements were made with a Spiegel-Relaskop. Total ages of the trees were obtained by adding 3 years to core samples obtained at diameter breast height. Acceptable variation in age between sample trees on any plot was limited to 10 years, and the average tree age of the study plots ranged from 33 to 73 years.

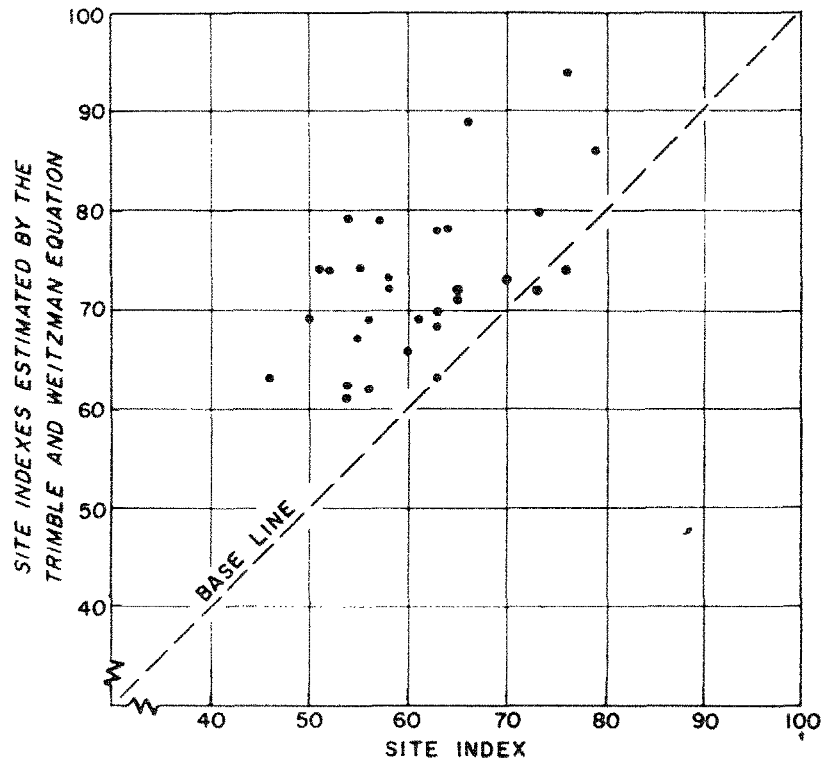
ANALYSIS AND RESULTS

The fit of the Trimble and Weitzman equation on the oak sites in the Ridge and Valley Region is graphically illustrated in figure 2. With the exception of three plots, their equation consistently overestimated site index by 3 to 25 feet. Had there been any semblance of fit, the points would have been about equally distributed above and below the 45-degee base line. Estimated and measured plot site indexes were treated as paired values in a t-test analysis, and differences between them were found to be significant beyond the 1-percent level.

The possibility of adjusting the predicted site-index values for the conditions in the Ridge and Valley Region was explored by calculating a regression line for the distribution shown in figure 2. The correlation coefficient that resulted is 0.562, and this is significant at the 1-percent level. Thus, correlation is found to exist but is somewhat lower than that desired to permit extension of the Trimble and Weitzman equation. However, the significant correlation coefficient did indicate that one or more of the site factors in their equation was important for predicting oak site index in the Ridge and Valley Region.

The remaining alternative, then, was to develop a separate site-index prediction equation for the Ridge and Valley Region. This necessitated sampling additional plots, and 27 plots were added to the study to make a total of 57.

Figure 2.—Comparison of site indexes predicted by the Trimble-Weitzman equation with site indexes determined from Schnur's curves for the plots in the Ridge and Valley Region.



Ten topographic and soil variables were analyzed by multiple regression to determine their usefulness as predictors. The ten variables are as follows: aspect, slope position, length of slope above the plot, percent slope, elevation, pH of the A_2 horizon, soil depth to a maximum of 6 feet, and the thickness of the A, A + B, and C horizons. In addition to these, selected interactions were also tried as independent variables.

The association of stand age and site index was also examined. From a scatter diagram a strong negative relationship was evident, and as a result average height was included with site index as a second dependent variable in the analysis.

Utilizing the 7090 IBM Computer, we were able to compute coefficients of multiple determination, R^2, for a large number of equations. This phase of the analysis represented a screening in which each independent variable, alone and in combination with other independent variables, could be evaluated in light of its contribution to the R^2. Transformations for specific variables were also screened where deviations from linearity were suspected, including the dependent variables that were transformed by the use of logarithms.

After a careful examination of all possible combinations, five independent variables emerged as the most efficient combination of components to retain in the final regression. These were: stand age, aspect, slope position, thickness of the A + B horizons, and pH of the A_2 horizon. All five variables were found to be significantly related to both site index and average tree height. However, the analysis showed that average tree height was better expressed as a function of the independent variables than was site index. The final equation relating age and the soil and topographic variables to tree height is:

$$\text{Logarithm of average tree height} = 1.8807 - 9.7538X_1 - .0336X_2 + .0006X_3 - .5071X_4 + .0261X_5$$

where the independent variables are expressed as:

X_1 = the reciprocal of stand age (1/stand age).

X_2 = aspect (the sine of the azimuth taken from SE and adding 1).

X_3 = Slope position (determined as the percent distance from the ridge line in relation to the total length of the slope).

X_4 = the reciprocal of the thickness of the A + B horizons in inches (1/A + B horizons).

X_5 = pH of the A_2 horizon

The significance of the partial regression coefficients and the amount of variance accounted for by each independent variable were determined (table 2). The multiple correlation coefficient for the equation is 0.824, and the standard error of estimate is ± 4.7 feet at the average height of 60 feet.

Table 2.—Independent variables and the amount of height variance accounted for by each in the equation

Variable	"t" values of the partial regression coefficients	Variance explained[1]
		(Percent)
Stand age	8.1229**	36.6
Aspect	3.9820**	8.1
Slope position	3.2447**	9.9
Thickness of A + B horizons	3.8907**	9.8
pH of the A_2 horizon	2.230*	3.5

[1] Determined as a ratio of the individual variable sum of squares and the total sum of squares.
* Indicates significance at 5-percent level.
** Indicates significance at 1-percent level.

Slight but significant correlations were noted between pH and slope position and between pH and stand age. The correlation coefficients were 0.278 and 0.274 respectively (significant at the 5-percent level). However, the relationship between pH and average tree height remained significant when the effects of slope position and stand age were removed.

The significance of pH cannot be explained because we did not make a chemical analysis of soil samples. The range of pH for the soils on the study plots was from 4.0 to 6.0. This range is within the limits of that generally accepted as suitable for hardwood growth *(Lutz and Chandler 1946)*. Rarely has pH appeared as a significant variable in other site studies. Thompson and McComb (*1962*) reported a significant correlation with site indexes of plantation-grown black walnut in Iowa. They were able to show that the relationship between pH and site index was in fact a reflection of calcium and potassium deficiencies.

As a predictor, the use of pH would be questionable in situations where the litter and humus layers have undergone a severe transition as in the case of heavy thinnings and on clear-cut areas. pH is not a stable variable and can be greatly influenced, especially in the surface horizons, by changes in stand condition.

Therefore it would be desirable to eliminate pH from the prediction equation. Without pH, the multiple correlation coefficient changes from 0.824 to 0.804, and the standard error of estimate is increased only slightly from ± 4.7 to ± 4.9 feet. The four-variable equation in the same order as before becomes:

$$\text{Log of average height} = 1.9964 - 9.0631X_1 - .0375X_2 + .0008X_3 - .5058X_4$$

Data for use as a field guide were computed with this equation (table 3). In the computations, 50 years was substituted for age (X_1), and only the three factors shown in the table need to be determined in field use.

The analysis also revealed the existence of several other relationships. A weak but significant correlation was found between soil depth measured to a maximum of 6 feet and stand height. Thickness of the A + B horizons revealed a much stronger relationship than total soil depth—probably because of greater measurement precision. With some soils, as in the Calvin series, total depth was difficult to determine because of the lack of a distinct boundary between the highly weathered shale parent material and the underlying bedrock.

Table 3.—Estimated site index of oak on medium-textured, well-drained sandstone and shale soils in the Ridge and Valley region of West Virginia and Maryland

Thickness A + B horizon (inches)	Slope position and aspect														
	Top (1 percent)			Upper (25 percent)			Middle (50 percent)			Lower (75 percent)			Bottom (99 percent)		
	SW	SE & NW	NE	SW	SE & NW	NE	SW	SE & NW	NE	SW	SE & NW	NE	SW	SE & NW	NE
6	45	49	54	47	52	56	50	54	59	52	57	62	54	59	65
12	50	54	59	52	57	62	55	60	65	57	62	68	60	65	71
18	52	56	61	54	59	64	56	62	67	59	64	70	62	68	74
24	52	57	62	55	60	65	57	63	68	60	66	71	63	69	75
30	53	58	63	55	60	66	58	63	69	61	66	72	64	69	76

There was an almost perfect inverse correlation between thickness of the C horizon and the combined depth of the A and B horizons. The correlation coefficient for this relationship was 0.994. However, the exceedingly high correlation shown here is misleading because a number of plots had soils that were in excess of the 6-foot maximum depth used in the analysis. Positive relationships also were observed between the depth of A + B horizons and the total soil depth, and between the depth of C horizon and the total soil depth. But their respective correlation coefficients, although significant, were only 0.417 and 0.321. The poor agreement indicated by the size of these coefficients emphasizes in part the difficulty of obtaining accurate total-depth measurements and the inadequacy of the arbitrary termination of solum thickness at 6 feet.

The analysis revealed that the length of the slope above the plot, which was considered as an alternative to slope position, was related to stand height, but not as strongly as was slope position.

No relationship was evident between the depth of the A horizon and stand height even though the depths of the A horizon ranged between 2 and 15 inches. However, this was not surprising in view of the nature of the root distributions observed. Generally, the major mass of fine roots was found to be evenly distributed throughout a depth that varied between 15 and 20 inches. The analysis bears out the observation that this root distribution occurred regardless of the depth of the A horizon.

Neither of the other two factors included in the analysis — percent slope and elevation — was significantly related to stand height.

DISCUSSION

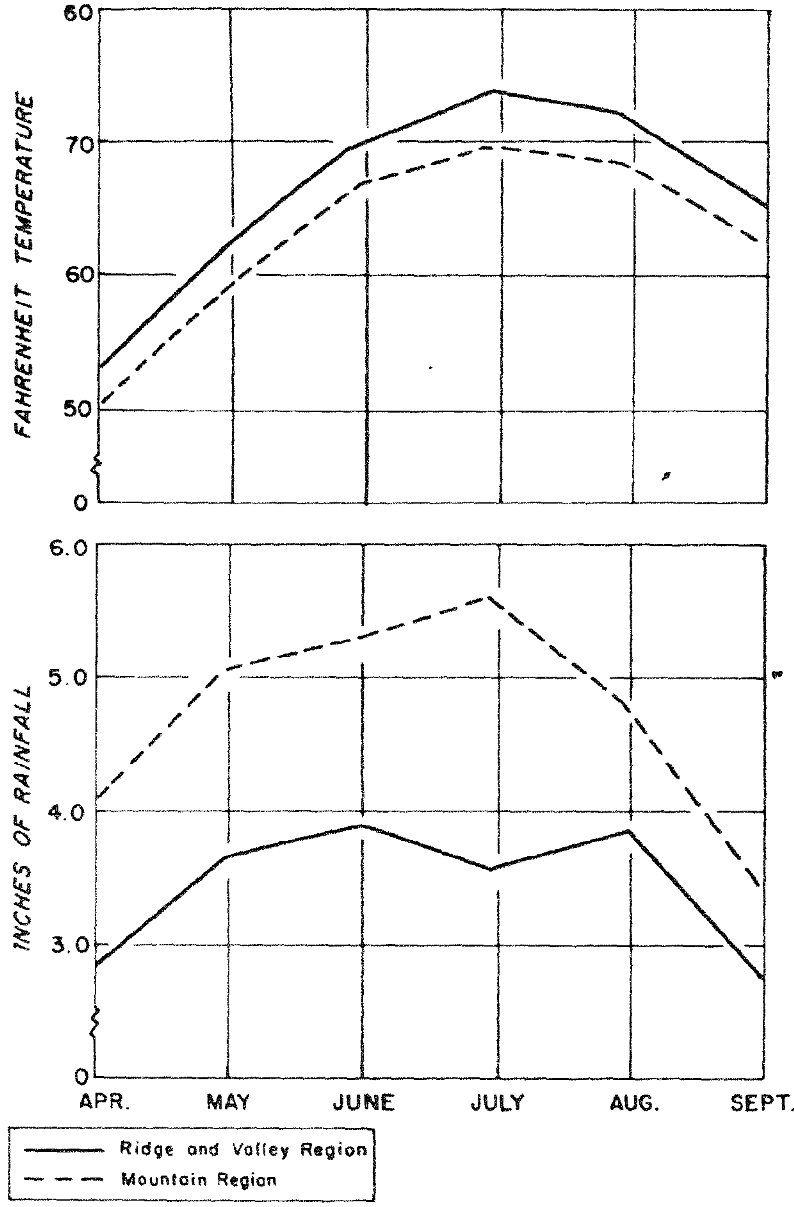
The analysis of the data clearly shows that the oak site index prediction equation developed by Trimble and Weitzman for the neighboring Mountain Region cannot be extended without considerable loss in prediction accuracy, either directly or by adjustment, to include the oak sites in the Ridge and Valley

Region. In similar trials with longleaf and slash pine, Hodgkins (*1956*) failed to achieve good correlations between predicted and measured site indexes in southwestern Alabama with several equations developed in other geographic regions of the South.

The failure of the Trimble Weitzman equation to predict oak site indexes in the Ridge and Valley Region can most likely be explained by the climatic differences that exist between the two regions. Average monthly temperatures and precipitation through the growing season based on 30 years of record are shown in figure 3. Precipitation for the Ridge and Valley Region is approximately 35 percent less than for the Mountain Region. Monthly temperatures for this period in the Ridge and Valley Region averaged 3.4° F. higher than in the Mountain Region. The greater evaporation and transpiration potential indicated by the higher temperatures, combined with lower rainfall, no doubt alters the oak growth patterns from that predicted by the Trimble and Weitzman equation. An estimate of the effects of these climatic differences on growth can be gained from the site index comparisons in figure 2. The productivity of sites having the same soil and topographic factors is fully one site class lower in the Ridge and Valley Region.

The full impact of the precipitation patterns on the growth of oak in the Ridge and Valley Region cannot be fully appreciated without reviewing the work done by Tryon and True (*1958*) in nearby Pocahontas County, West Virginia. Their investigation dealt with reductions in annual radial increment of scarlet oak as related to rainfall deficiencies. This study covered the years 1949 to 1956. During this period, droughts were recorded in 1949, 1951, 1953, and 1955. The effect of these successive droughts was a general decline in the growth rates. Reductions in radial increment were shown to occur during the growing seasons after the drought years and were related to dry periods during the months of July to September of the previous year. The portion of the Ridge and Valley Region covered by our soil-site study was similarly subjected to the same repeated droughts, and the implication is that the oak in this area suffered the same growth losses.

Figure 3.—Comparison of average (1931 to 1960) monthly temperatures and precipitation during the growing season in the Ridge and Valley Region of West Virginia and Maryland and the neighboring Mountain Region of West Virginia.



Long-term precipitation records reveal that extended dry periods during mid-summer and late summer are not at all uncommon. It follows that the accumulative effect of the periodic soil-moisture deficiencies chronic to the Ridge and Valley Region is to alter the oak growth patterns from that observed in other parts of the northern red oak range.

SUMMARY

A soil-site study was made in the Ridge and Valley Region of northeastern West Virginia and western Maryland to evaluate the relationship between several environmental factors and the growth of oak trees.

As a first step, we determined whether or not an oak site index estimating equation previously developed in the Mountain Region immediately to the west was applicable or could be adapted to the Ridge and Valley area. Statistical analysis indicated that it could not be applied without a drastic reduction in estimation precision. This meant that a separate equation was needed. Such an equation was developed from data taken on 57 plots on well-drained medium-textured soils derived from sandstone and shale parent materials.

A large number of variables were examined to determine their relationships to both oak site index and average tree height. The analysis showed that the greatest possible amount of the variance observed in either site index or average tree height was accounted for by the same five independent variables. These are: stand age, aspect, slope position, thickness of the A + B horizons, and pH of the A_2 horizon. Because of greater estimating precision, the equation was developed on the basis of average tree height with the resulting multiple correlation coefficient of 0.824 and a standard error of estimate of $\pm$ 4.7 feet at the average tree height of 60 feet. Stand age was by far the most important single independent variable: it accounted for more than half of the total explained variance.

The data developed in this study made it possible to compare oak site indexes between the Ridge and Valley Region and the

adjoining Mountain Region. Site indexes were considerably lower in the Ridge and Valley Region for sites with similar soils and topographic conditions. These differences are attributed to the lower rainfall and higher growing-season temperature.

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