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Oak Soil-Site Relationships in NORTHWESTERN WEST VIRGINIA



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Abstract

An oak soil-site productivity equation was developed for the well-drained, upland soils in the northwestern portion of West Virginia adjacent to the Ohio River. The equation uses five easily measured soil and topographic variables and average precipitation to predict site index. It accounts for 69 percent of the variation in oak site index and has a standard error of 4.3 feet at the mean site index of 67.6 feet. The equation was tested with data from 61 independent plots, and the results showed a correlation of 0.83 between predicted and observed site indexes.

INTRODUCTION

NUMEROUS STUDIES have related forest productivity in a given area to various soil and topographic features of the landscape. Six such studies have been completed for oaks in parts of West Virginia, western Maryland, Ohio, and Pennsylvania (Gaiser 1951, Trimble and Weitzman 1956, Yawney 1964, Carmean 1965, Yawney and Trimble 1968, Bowersox and Ward 1972). In addition, many other site studies have confirmed the importance of aspect, position on slope, and slope steepness as well as soil depth, texture, and drainage for predicting site quality of a large number of species (Carmean 1970, 1973, 1975).

In northwestern West Virginia, oaks are the dominant hardwoods, but a large portion of these stands are unsuitable for direct site index determinations because of early suppression, previous partial cuttings, and detrimental land use such as grazing, or fire and erosion. The purpose of this study was to derive an equation that could be used by foresters and land managers to predict oak site quality from easily measured soil and topographic variables where suitable stands for direct site index determinations are not present.

STUDY AREA

This study was conducted in northwestern West Virginia (Fig. 1; see Appendix for all figures), an area that contains about 1.3 million acres of upland oak forests (Ferguson 1964). The region is characterized by similar recurring topographic patterns, several major soil series and their intergrades, and an annual precipitation from 40 to 48 inches. Elevation ranges from about 600 feet in the valley bottoms to about 1,400 feet on the ridges and

upper flats. The terrain varies from gently rolling topography on upland flats to the steep side walls of narrow valleys that exceed 50 percent slope.

The major forest types of the upland portion of the region are dominated by five species of oak: red oak (*Quercus rubra* L.), black oak (*Q. velutina* Lam.), white oak (*Q. alba* L.), scarlet oak (*Q. coccinea* Muenchh.), and chestnut oak (*Q. prinus* L.). Red oak is most abundant on the better sites, but is frequently found throughout the range of sites. Black and scarlet oak are found primarily as scattered individuals. White oak, often found in nearly pure stands—though also mixed with the other oaks—is most abundant on dry southern exposures. Chestnut oak usually dominates the ridge tops and the poorest sites. In the best stands, which are located on deep, moist soils in coves and on concave middle and lower slopes of northern exposures, oaks are generally found only as scattered individuals mixed with yellow-poplar (*Liriodendron tulipifera* L.).

The majority of the upland soils within the region are residual, having formed in parent material weathered from the Dunkard geologic formation. The Dunkard formation consists of alternating strata of acid gray sandstone and siltstone, and red clay shale, which gives rise to greatly contrasting soils where these different strata surface. Much of the area has been affected by erosion and colluvial deposition, and has developed bench-slope topography with an intricate soil complex. Three major soil series—Muskingum, Gilpin, and Upshur—and their intergrades were recognized in this study.

The major land use for the entire area was once agriculture, and the degree to which existing forest land was affected by sheep and cattle grazing is not known. Much of the original farmland has since reverted to timber.

Fires have been numerous and widespread, and erosion on much of the area was prevalent in the past.

STUDY METHODS

We established 91 plots in fully-stocked, even-aged oak stands that showed no evidence of past cutting, and which appeared free of fire and grazing in recent years. Only stands ranging in age from 40 to 70 years and on well-drained sites with uniform soils and surface configuration were sampled.

On each plot, a minimum of 10 dominant and codominant oaks were measured for total height and age at breast height, and then combined for an average oak site index.¹ The trees measured were those growing nearest to the plot center and that showed no evidence of previous top breakage or suppression. Height measurements were taken during the leafless period to ensure accuracy. Three years were added to the age to arrive at total age. The plots ranged in size from about 0.1 to 0.4 acre to include the prescribed number of trees.

Three evenly spaced soil pits were dug on each plot to bedrock or 6 feet, whichever was shallowest. The soil series or intergrade was identified. Thickness, pH, Munsell color, texture (feel-at-the-pit method), and stone content of each horizon were determined. Values from the three pits were averaged to represent the plot. Ten supplementary A_1 thickness determinations were made on each plot and averaged with the A_1 data from the soil pits.

Topographic information on each site included: aspect, slope steepness, distance to ridge or upper flat, total slope length, azimuth and angle to highest surrounding land, lateral slope shape, and land form. Values for precipitation were obtained from published climatic tables (Grafton and Dickerson 1969). Elevation, latitude, and longitude were determined from U.S. Geological Survey (USGS) topographic maps. The solar radiation reach-

ing each plot during the growing season and the radiation index based on aspect, slope steepness, and latitude were calculated from published tables (Frank and Lee 1966). Stand age was determined from increment cores and expressed as its reciprocal. The site index was determined from existing height/age curves (Schnur 1937).

Forty-six independent variables and transformations for predicting stand height, site index, and log site index were evaluated by multiple regression with backward elimination procedures (Draper and Smith 1966). The relationship between site index and aspect (azimuth) was computed by entering the sine and cosine of azimuth $\times$ slope steepness and slope steepness as three separate independent variables according to the procedure described by Stage (1976).

The final prediction equation was tested for field application by comparing the predicted values to the observed site indexes derived from an independent study on 61 soil-site plots.² These plots were located within the study region and included the same soil series as well as six others.

RESULTS

Data collected in this study show that the site index for oak within the region ranges from a low of 47 to a high of 85 (Table 1; see Appendix for all tables). However, both poorer and more productive sites may exist that were not included in our sampling. The mean site index among soils varied only slightly and differences among soils were not significant ($P \leq 0.05$), which indicates that other factors are important for tree growth.

The equation

Because there were no overall differences in site quality among the different soils, data were combined to derive a prediction equation applicable to all well-drained residual soils of the uplands. Of the 46 independent variables that were originally tested (see Appendix), 6 were significantly related to site index ($P \leq$

¹Combining species that have known differences in site index represents an unaccountable source of variation in the derived prediction equation. However, from a practical standpoint, mixed stands of oak are far more common than pure stands, and "oak species" allows for the use of existing yield tables that are applicable to the region.

²These data were provided by John L. Gorman, Woodland Conservationist, Soil Conservation Service, Morgantown, W. Va.

0.05). The same six were also strongly correlated with stand height and the log of site index, but multiple coefficients of determination (R^2) were slightly less than with site index. The regression equation selected is:³

$$Y = -b_0 + 2.897 (X_1) + [7.026 (X_2) \times \cos (X_3)] - 9.216 (X_2) + 2.859 (X_4) + 0.081 (X_5)$$

where:

Y = site index (height at age 50, in feet)
 b_0 = slope shape—a discrete variable expressed numerically as follows:

convex slope = -58.761

linear slope = -55.988

concave slope = -52.377

X_1 = thickness of A_1 soil horizon (inches)

X_2 = slope gradient (percent slope/100)

X_3 = aspect (azimuth of the plot minus 81°)

X_4 = precipitation (inches to a maximum of 44)

X_5 = position on slope (percentage of total slope length)

With the exception of slope gradient, prediction variables are significant at the 0.05 level. The strongest predictors of site index are thickness of the A_1 soil horizon and aspect. When individual prediction variables were regressed separately with site index, the quantities of explained variation were:

Variable	R^2 (percent)
A_1 thickness (X_1)	44
Aspect (X_2) and slope gradient (X_3)	20
Precipitation (X_4)	9
Position on slope (X_5)	3

Correlations among independent variables were significant ($P \leq 0.05$) only between the thickness of the A_1 soil horizon and the aspect ($r = 0.26$). The remaining independent variable correlations were less than 0.20 and most

were less than 0.10, which suggests that the prediction equation is relatively free of inter-correlation problems.

Equation verification

The equation was tested against independent data from 61 soil-site plots. The correlation coefficient between predicted and observed site index was 0.83, significant beyond the 0.01 level. The regression equation accounted for 69 percent of the variation in predicted site index and had a standard error of estimate of 4.3 feet, essentially identical to the fit of the original prediction equation (Fig. 2). Seventy-two percent of the predicted values were within five points of the observed site index. Of the 61 predictions, 69 percent overestimated and 31 percent underestimated the measured site index. Although there is a strong correlation between predicted and actual site index, the equation tends to over-predict by approximately two site index points with this data set. Nevertheless, we feel that its accuracy is sufficient for field use since most deviations are within the error of practical determination.

Independent variables

Each soil and topographic variable in the equation has a biological implication—directly or indirectly they describe the moisture regime, the soil depth, or the fertility of the site. Each variable, as used in the equation, is approximately linear over the range of conditions sampled.

A_1 thickness (X_1). Thickness of the A_1 soil horizon varies with aspect (correlation coefficient = 0.26); the horizon is of minimal thickness on dry west and southwestern exposures, intermediate on southeastern and northwestern exposures, and maximum on east and northeastern-facing slopes. Depth of the A_1 also is influenced (but not statistically with these data) by species composition of the existing stand—whether the slope is convex, concave, or linear—and by the position of the site on the slope. On southwestern and west-facing slopes, increasing slope gradient is accompanied by decreasing A_1 thickness, but slope gradient has only a minor influence on the A_1 horizon on favorable aspects. Site

³The equation also includes the reciprocal of stand age as a variable to correct site index values for differences between the height/age curves used to determine site index and the actual height/age patterns of our sample. However, when the equation is used to predict site index at age 50, this variable becomes a constant, and has therefore been incorporated into the b_0 's to simplify the equation.

quality increases by about three site index points for each additional inch of A_1 soil horizon.

Generally, the A_1 thickness is least on steep, convex, southwestern exposures on the upper 25 percent of the slope in stands dominated by oak. It is maximum on concave, north-eastern exposures on the lower 25 percent of slopes where yellow-poplar and basswood (*Tilia americana* L.) are major stand components. The A_1 thickness is an indicator of soil fertility and particularly of the site's capacity to supply nitrogen.

Slope gradient (X_2). Slope gradient is used in the equation to modify the amplitude of the cosine function of azimuth. In effect, it provides for the negligible influence of aspect on flat or gently sloping terrain and on favorable eastern exposures, but allows the equation to describe increasingly adverse conditions with increasing slope gradient on unfavorable western aspects (Fig. 3). On eastern exposures, site index decreases only one point with a 40 percent increase in slope steepness, but on western exposures it decreases two site index points for each 10 percent slope increase.

Aspect (X_3). Aspect is expressed in the equation as the cosine of azimuth with a phase shift angle of 81° from north which is modified by slope gradient. The cosine transformation imposes approximate linearity between site index and azimuth. The phase shift angle of 81° places the best sites at $N81^\circ E$ and the least productive at $S81^\circ W$, a shift of 23° to 35° further east than the normal 45° to 58° shift used for adjustment in most other soil-site investigations.

Site quality varies only slightly within $\pm 45^\circ$ of $N81^\circ E$ and $S81^\circ W$, even on slopes with gradients exceeding 50 percent; on slopes with grades less than 10 to 15 percent, the influence of aspect is negligible (Fig. 3). For the average 35 percent slope within the study region, site quality varies about 5 site index

points from the most favorable to the least favorable aspects. However, this change in aspect is normally accompanied by a large change in thickness of the A_1 soil horizon (deeper A_1 's on northern and east-facing slopes) expanding the site index spread to about 13 points.

Precipitation (X_4). Small increases in precipitation during the summer when forests are subject to intermittent soil moisture stress are important for increasing site productivity. Within the study region, rainfall generally increases from west to east and from south to north. Site index increases directly with increasing precipitation from the 40- to the 44-inch level at a rate of three site index points per additional inch of precipitation. There was no relationship between site index and precipitation above 44 inches.

Position on slope (X_5). Upper slope positions usually have the driest, stoniest, and shallowest soils with a minimal A_1 soil horizon. In contrast, lower slopes have deeper soils that are frequently more moist, sometimes stone-free, and with maximum A_1 accumulation. Site index increases by about six points from upper to lower slopes, although frequently there are larger differences if the A_1 thickness increases with increasing distance from the ridge. Although not considered in the equation, a rapid decline in site quality often occurs on near-crest positions due to shallow soils.

Slope shape (b_0). Slope shape is a discrete variable that refers to the lateral topographic configuration of the slope. Convex slopes are generally drier and have shallower and more stony soils than concave slopes; linear slopes lie in an intermediate position. In general, site quality is lowest on convex upper slopes and highest on lower slopes with concave relief. Site index varies by three points between convex and linear and between linear and concave slopes. Concave land forms are often associated with greater A_1 depths than either linear or convex topography.

APPLICATION OF THE EQUATION

Once the values for the independent variables have been determined, site index can be accurately and rapidly determined from Table 2 or computed directly from the equation by a pocket calculator or with simple additions and multiplications.

Measuring the independent variables

Six values are needed to compute site index. Aspect (X_3) and position on slope (X_5) can be obtained from USGS topographic sheets or by field measurements. Thickness of the A_1 soil horizon (X_1), slope shape (b_o), and slope gradient (X_2) must be determined onsite. Precipitation (X_4) is determined easily from the map (Fig. 4). Determinations are made as follows:

Thickness of the A_1 soil horizon (X_1). The A_1 horizon consists of the uppermost layer of mineral soil. It lies just beneath the litter and humus layers, and is partly mineral (soil) and partly organic. This horizon can be distinguished from the soil horizon directly beneath it by its darker color and higher content of organic matter. And it can be distinguished from the overlying humus, which has no mineral soil (in some soils there will not be a humus layer).

The A_1 thickness varies considerably from point to point—even within short distances—so a number of determinations *must* be made. The number of samples required for good average estimates cannot be predetermined, since sampling requirements depend on the size of the area for which site index is being predicted and upon the soil heterogeneity.

As a general sampling guide, we suggest that approximately 15 determinations be made for each 10 acres if the area is relatively uniform. For larger acreages, and for those that are heterogeneous, more samples will be necessary. The final estimate should represent the mean A_1 thickness to the nearest half inch. Measurements can be made rapidly with a punch-tube soil auger in a random traverse over the area; however, it is important that a representative average for the entire tract be obtained.

Slope gradient (X_2). Determine the average slope steepness with a hand level to the nearest 10 percent slope. Divide percent slope by 100 for use in the equation.

Aspect (X_3). Aspect refers to the orientation of the site facing downslope perpendicular to the contour. Obtain the azimuth with a hand compass or from a USGS topographic sheet. If the equation is to be used for the computation, use the proper transformed cosine value from Table 3.

Precipitation (X_4). Use the average precipitation for the site to the nearest inch as shown on the map in Figure 4. For precipitation levels greater than 44 inches, use 44 in the equation and in the site index table.

Position on slope (X_5). Slope position is the distance from the plot to the ridge expressed as a percentage of total slope length. Areas located near the top of a slope have values approaching zero and those near the bottom of the slope, approaching 100. Total slope length and distance to the slope crest can usually be estimated near enough for practical purposes without the need for actual measurements.

Slope shape (b_o). Visually estimate the overall landform—whether the slope is convex, linear, or concave in a lateral direction. In the equation, assign a value of -58.761 for convex slopes, -55.988 for linear slopes, and -52.377 for concave slopes.

An example

To illustrate how to use the equation, assume that the following data were obtained from a forest site in Doddridge County:

b_o = slope shape—linear (use -55.988).

X_1 = thickness of A_1 soil horizon—2 inches (onsite determination).

X_2 = slope gradient—30 percent slope = $30/100 = 0.30$ (onsite determination). For slopes greater than 50 percent, use 0.50 as the gradient in Table 2.

X_3 = aspect—Az. $45^\circ = 0.8090$. Azimuth determined onsite or from USGS maps. Cosine values for use with the equation are in Table 3. Use the azimuth value in Tables 2 and 3 that is nearest the actual value.

X_1 = Precipitation—47 inches (Fig. 4).
 Since precipitation exceeds the maximum permitted, use 44 in the equation or enter the site index table at the 44-inch precipitation level.

X_5 = Position on slope—25 percent downslope (determined onsite or from USGS maps).

Estimating site index by Table 2. Table 2 is arranged for easy field reference, with site index predictions for aspect, A_1 thickness, position on slope, and slope shape for three slope gradients by 1-inch precipitation increments. To use the table, first select the slope gradient that is nearest to the field estimate, then select the proper precipitation rate and determine the site index that corresponds with the proper aspect, A_1 thickness, position on slope, and lateral slope shape of the tract. Extrapolation of site index for untabulated independent variable values can easily be made, if needed.

For this first example, locate the tabulations in Table 2 that correspond to a slope gradient of 0.30 and a precipitation level of 44 inches. Since the area for which site index is being estimated has an azimuth of 45° and an A_1 thickness of 2 inches, enter the table on line 6 and move to the second column that represents linear landforms on the upper 25 percent of slopes. The predicted site index is 75.

Using a different plot located on a linear slope with a gradient of 0.30, azimuth of 45° , precipitation of 44 inches, but with a 3-inch A_1 thickness and situated near the base of the slope, the site index would be 84 (Table 2).

Estimating site index with the equation. For the first example, substitute the values for the independent variables in the equation, multiply each coefficient by the proper value, and then algebraically sum the resulting figures. Thus, to compute a site index with the equation, substitute -55.988 for slope shape, 2 inches for A_1 , 0.30 for slope gradient, 0.8090 for 45° azimuth (obtained from Table 3), 44 inches for precipitation, and 25 for slope position.

$$\begin{aligned} \text{Site index} = & - \text{slope shape} \\ & + 2.897 (A_1 \text{ thickness}) \\ & + 7.026 (\text{percent slope}/100) \\ & \times \text{Cos (azimuth)} \\ & - 9.216 (\text{percent slope}/100) \\ & + 2.859 (\text{precipitation}) \\ & + 0.081 (\text{position}) \end{aligned}$$

$$\begin{aligned} \text{Site index} = & -55.988 + 2.897 \times 2 + (7.026 \\ & \times 0.30 \times 0.8090) - 9.216 \times \\ & 0.30 + 2.859 \times 44 + 0.081 \times 25 \end{aligned}$$

$$\text{Site index} = 76.6$$

The discrepancy between calculated and tabulated site indexes is due to rounding and from computing the values for the midpoints of the four slope positions for Table 2. Thus, values shown in Table 2 for the upper 25 percent portion of slopes are calculated for a distance 12.5 percent downslope from the ridge, those for the upper 25 to 50 percent portion actually represent the site index position that is 37.5 percent of the way down from the ridge, etc.

Precautions

To predict site index, there is no need to identify specific soils, but it is important to remember that both the equation and Table 2 were developed only for upland residual soils that are well drained. The equation and Table 2 *do not* apply to bottom lands, river terraces, or to upland soils that are not well drained, and should not be used for these situations.

Occasionally specific sites may not fit the general pattern of site quality that is indicated by the equation. In these cases the influencing factor is likely to be soil depth, since it is an important determinant of site quality but is considered only indirectly in the equation by position on slope and slope shape. Therefore, if an obviously deep soil happens to occupy an upper convex slope or if a shallow soil occurs on a steep lower slope, the predicted site index should be adjusted for soil depth. We suggest that 3 to 4 site index points be added to

the predicted value for upper slopes with deep soils, and 3 to 4 points subtracted from sites on lower slopes that have soils less than 3 feet deep.

Because the primary independent variable in the equation is the thickness of the A₁ soil horizon, the equation is not applicable to open agricultural land or to other disturbed sites where the A₁ thickness has not stabilized.

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APPENDIX

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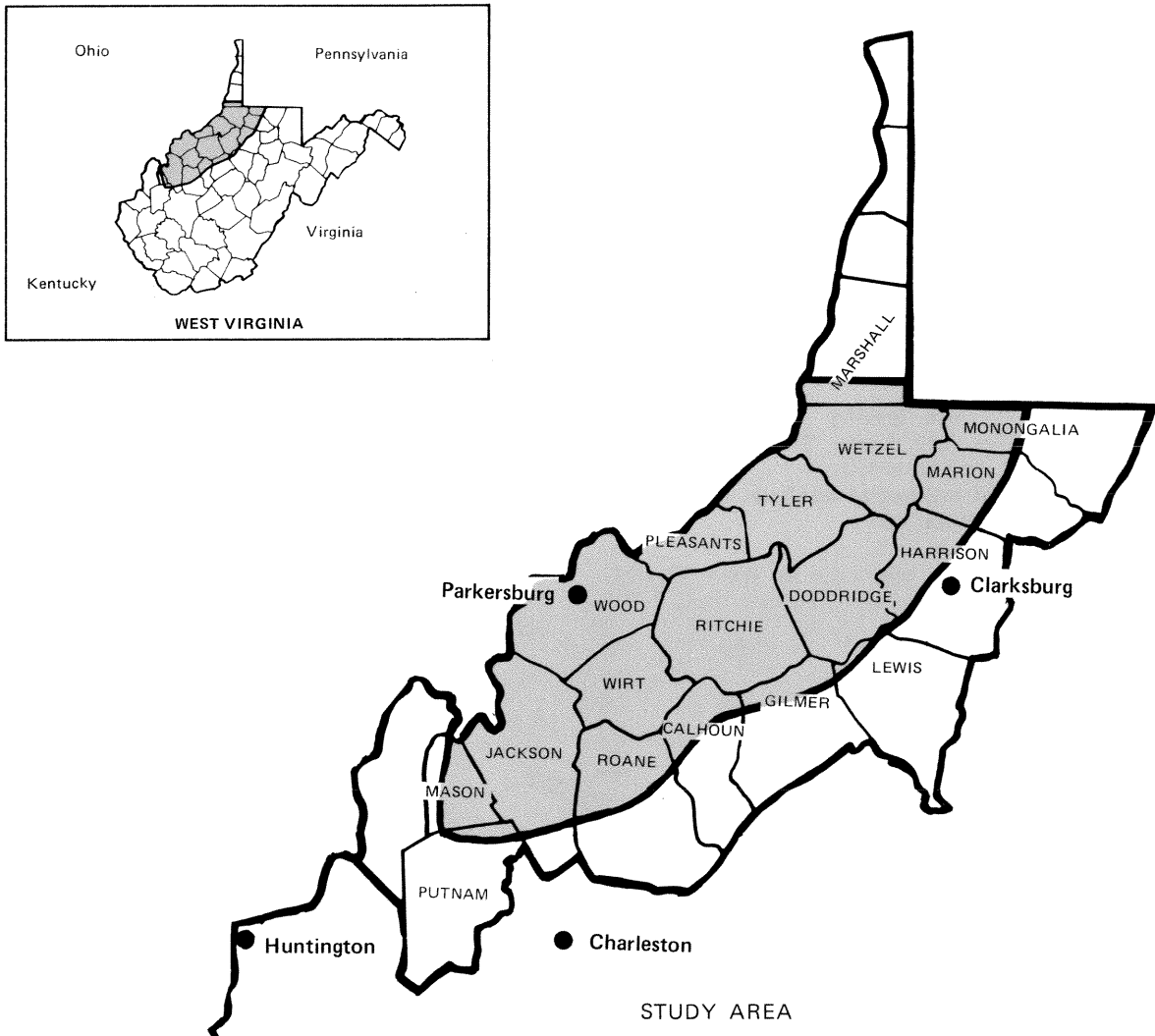


Figure 1. The region studied includes about 3 million acres of forest land in northwestern West Virginia. Region boundaries are delineated by uniform climate, topographic configuration, and geologic formation from which the dominant soils have formed.

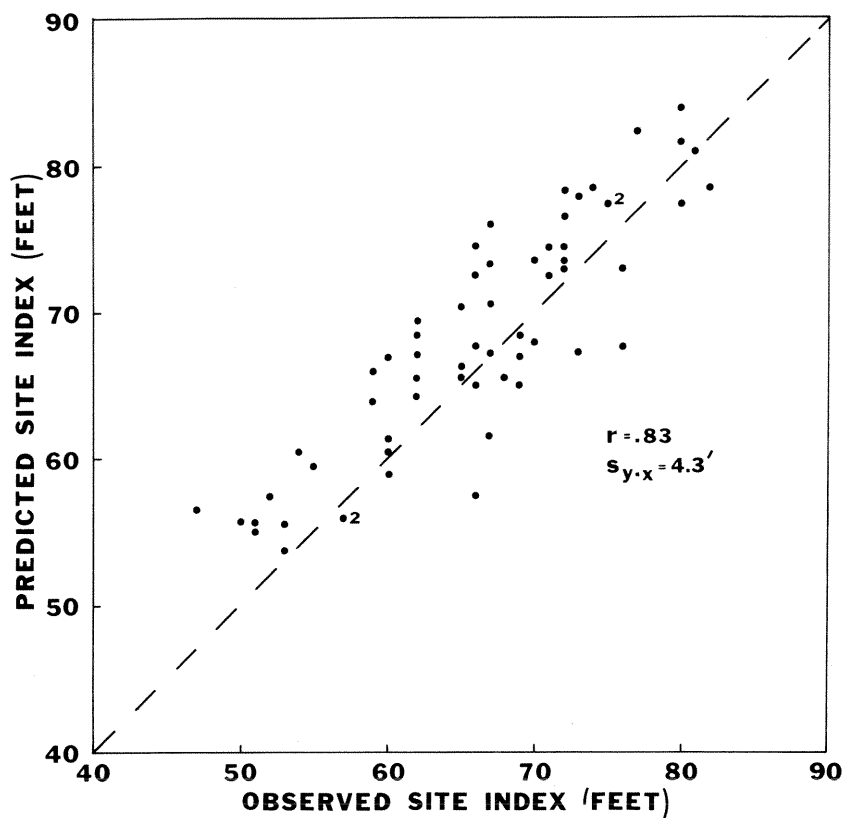


Figure 2. The relationship between predicted and observed site index for 61 independent test plots. The dashed line represents perfect 1:1 correlation. The equation overpredicts with this data set by about two site index points.

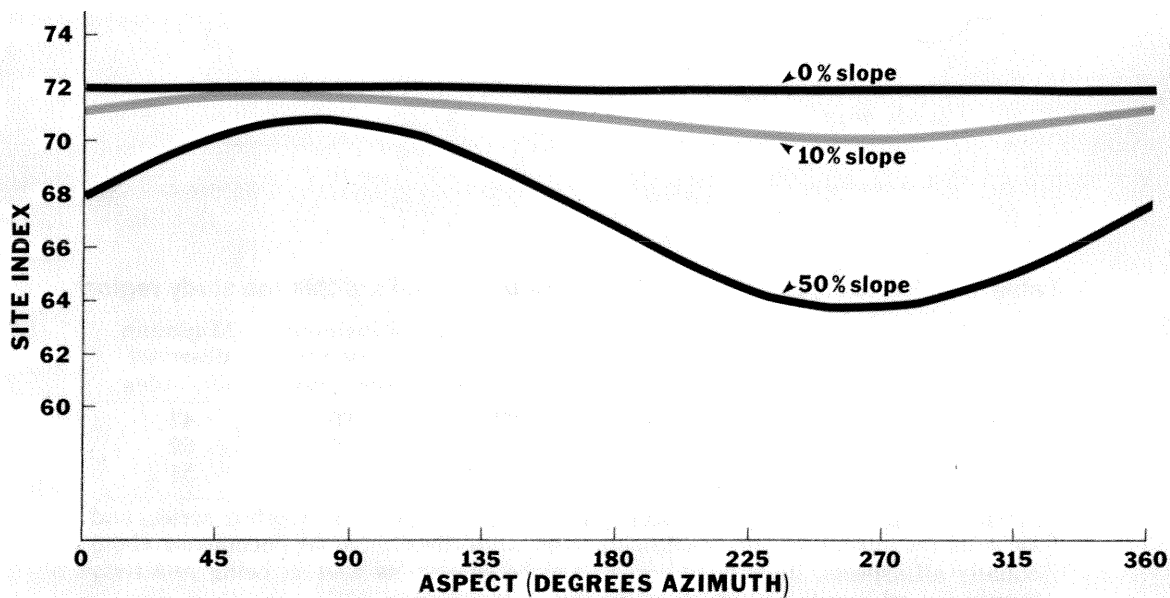


Figure 3. The relationship between site index and aspect as affected by slope gradient.

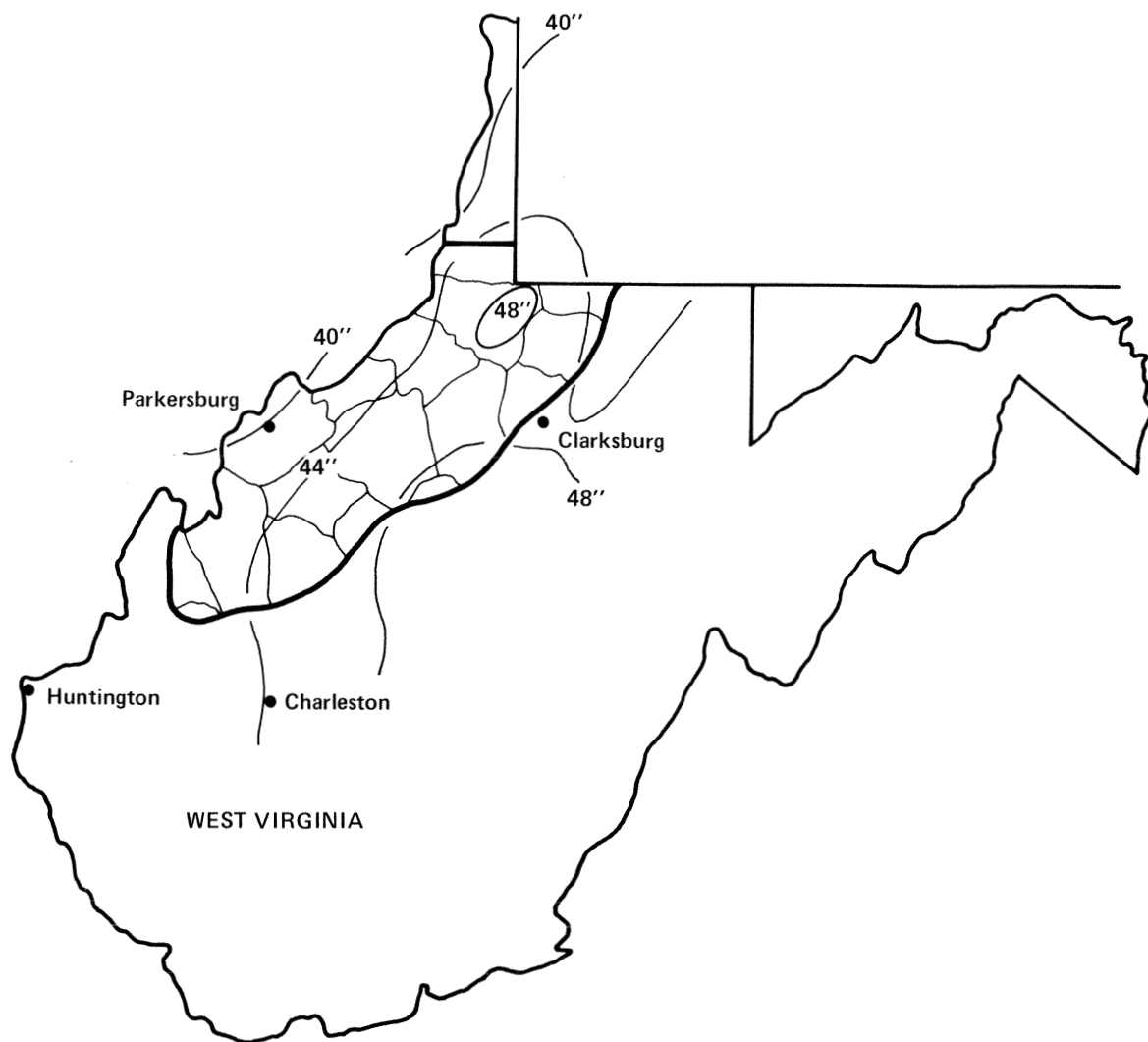


Figure 4. Average annual precipitation in the West Virginia study area.

Table 1. Oak site index values for the major upland soils within the study region^a

Soil	Mean site index	Confidence limits (05 level)	Maximum observed site index	Minimum observed site index
Gilpin/Muskingum ^b	69	67-72	80	47
Upshur	67	63-71	80	52
Intergrades	70	67-72	85	55

^aIncludes 28 plots on Gilpin/Muskingum series, 19 plots on Upshur series, and 44 plots on integrades. For each soil, plots were distributed to encompass about equally all aspects, slope positions, and slope shapes, as well as being relatively evenly spaced over the entire study region.

^bGilpin/Muskingum series were combined because the sample was small for each series and their site index values were very similar.

Table 2. Predicted oak site index by slope gradient (.10, .30, .50) and precipitation (40 to 44 inches) in relation to azimuth, A₁ soil horizon thickness, position on slope, and lateral slope shape

Azi- muth	A ₁ depth	Upper 25% slope			Upper 25-50% slope			Lower 50-75% slope			Lower 75-100% slope		
		Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave
SLOPE GRADIENT = 0.10													
0	1	58	61	65	60	63	67	62	65	69	64	67	71
0	2	61	64	67	63	66	69	65	68	72	67	70	74
0	3	64	67	70	66	69	72	68	71	74	70	73	76
0	4	67	70	73	69	72	75	71	74	77	73	76	79
PRECIPITATION = 40													
45	1	59	61	65	61	63	67	63	65	69	65	67	71
45	2	62	64	68	64	66	70	66	68	72	68	70	74
45	3	64	67	71	66	69	73	68	71	75	71	73	77
45	4	67	70	74	69	72	76	71	74	78	73	76	80
90	1	59	62	65	61	64	67	63	66	69	65	68	71
90	2	62	64	68	64	66	70	66	68	72	68	71	74
90	3	65	67	71	67	69	73	69	71	75	71	73	77
90	4	67	70	74	69	72	76	72	74	78	74	76	80
135	1	58	61	65	61	63	67	63	65	69	65	67	71
135	2	61	64	68	63	66	70	65	68	72	67	70	74
135	3	64	67	71	66	69	73	68	71	75	70	73	77
135	4	67	70	74	69	72	76	71	74	78	73	76	80
180	1	58	61	64	60	63	66	62	65	68	64	67	70
180	2	61	64	67	63	66	69	65	68	71	67	70	73
180	3	64	67	70	66	69	72	68	71	74	70	73	76
180	4	67	69	73	69	71	75	71	73	77	73	75	79
225	1	58	60	64	60	62	66	62	64	68	64	66	70
225	2	60	63	67	62	65	69	64	67	71	66	69	73
225	3	63	66	70	65	68	72	67	70	74	69	72	76
225	4	66	69	73	68	71	75	70	73	77	72	75	79
270	1	57	60	64	59	62	66	61	64	68	63	66	70
270	2	60	63	67	62	65	69	64	67	71	66	69	73
270	3	63	66	70	65	68	72	67	70	74	69	72	76
270	4	66	69	72	68	71	74	70	73	77	72	75	79
315	1	58	60	64	60	62	66	62	64	68	64	67	70
315	2	61	63	67	63	65	69	65	67	71	67	69	73
315	3	63	66	70	65	68	72	68	70	74	70	72	76
315	4	66	69	73	68	71	75	70	73	77	72	75	79

CONTINUED

Table 2.—Continued

Azi- muth	A ₁ depth	Upper 25% slope			Upper 25-50% slope			Lower 50-75% slope			Lower 75-100% slope		
		Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave
SLOPE GRADIENT = 0.10													
PRECIPITATION = 41													
0	1	61	64	67	63	66	69	65	68	71	67	70	73
0	2	64	67	70	66	69	72	68	71	74	70	73	76
0	3	67	70	73	69	72	75	71	74	77	73	76	79
0	4	70	73	76	72	75	78	74	77	80	76	79	82
45	1	62	64	68	64	66	70	66	68	72	68	70	74
45	2	64	67	71	66	69	73	68	71	75	70	73	77
45	3	67	70	74	69	72	76	71	74	78	73	76	80
45	4	70	73	77	72	75	79	74	77	81	76	79	83
90	1	62	64	68	64	66	70	66	68	72	68	70	74
90	2	65	67	71	67	69	73	69	71	75	71	73	77
90	3	67	70	74	69	72	76	71	74	78	73	76	80
90	4	70	73	77	72	75	79	74	77	81	76	79	83
135	1	61	64	68	63	66	70	65	68	72	67	70	74
135	2	64	67	71	66	69	73	68	71	75	70	73	77
135	3	67	70	74	69	72	76	71	74	78	73	76	80
135	4	70	73	76	72	75	78	74	77	80	76	79	82
180	1	61	64	67	63	66	69	65	68	71	67	70	73
180	2	64	66	70	66	69	72	68	71	74	70	73	76
180	3	67	69	73	69	71	75	71	73	77	73	75	79
180	4	70	72	76	72	74	78	74	76	80	76	78	82
225	1	60	63	67	62	65	69	64	67	71	66	69	73
225	2	63	66	70	65	68	72	67	70	74	69	72	76
225	3	66	69	73	68	71	75	70	73	77	72	75	79
225	4	69	72	75	71	74	77	73	76	79	75	78	82
270	1	60	63	67	62	65	69	64	67	71	66	69	73
270	2	63	66	70	65	68	72	67	70	74	69	72	76
270	3	66	69	72	68	71	74	70	73	76	72	75	78
270	4	69	72	75	71	74	77	73	76	79	75	78	81
315	1	61	63	67	63	65	69	65	67	71	67	69	73
315	2	63	66	70	65	68	72	67	70	74	69	72	76
315	3	66	69	73	68	71	75	70	73	77	72	75	79
315	4	69	72	76	71	74	78	73	76	80	75	78	82

CONTINUED

Table 2.—Continued

Azi- muth	A ₁ depth	Upper 25% slope			Upper 25-50% slope			Lower 50-75% slope			Lower 75-100% slope		
		Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave
SLOPE GRADIENT = 0.10													
0	1	64	67	70	66	69	72	68	71	74	70	73	76
0	2	67	70	73	69	72	75	71	74	77	73	76	79
0	3	70	72	76	72	75	78	74	77	80	76	79	82
0	4	73	75	79	75	77	81	77	79	83	79	81	85
PRECIPITATION = 42													
45	1	64	67	71	66	69	73	68	71	75	70	73	77
45	2	67	70	74	69	72	76	71	74	78	73	76	80
45	3	70	73	77	72	75	79	74	77	81	76	79	83
45	4	73	76	79	75	78	81	77	80	83	79	82	86
90	1	64	67	71	67	69	73	69	71	75	71	73	77
90	2	67	70	74	69	72	76	71	74	78	73	76	80
90	3	70	73	77	72	75	79	74	77	81	76	79	83
90	4	73	76	80	75	78	82	77	80	84	79	82	86
135	1	64	67	71	66	69	73	68	71	75	70	73	77
135	2	67	70	73	69	72	76	71	74	78	73	76	80
135	3	70	73	76	72	75	78	74	77	80	76	79	82
135	4	73	76	79	75	78	81	77	80	83	79	82	85
180	1	64	66	70	66	68	72	68	70	74	70	73	76
180	2	67	69	73	69	71	75	71	73	77	73	75	79
180	3	69	72	76	72	74	78	74	76	80	76	78	82
180	4	72	75	79	74	77	81	76	79	83	78	81	85
225	1	63	66	70	65	68	72	67	70	74	69	72	76
225	2	66	69	73	68	71	75	70	73	77	72	75	79
225	3	69	72	75	71	74	77	73	76	79	75	78	81
225	4	72	75	78	74	77	80	76	79	82	78	81	84
270	1	63	66	69	65	68	72	67	70	74	69	72	76
270	2	66	69	72	68	71	74	70	73	76	72	75	78
270	3	69	72	75	71	74	77	73	76	79	75	78	81
270	4	72	75	78	74	77	80	76	79	82	78	81	84
315	1	63	66	70	65	68	72	67	70	74	69	72	76
315	2	66	69	73	68	71	75	70	73	77	72	75	79
315	3	69	72	76	71	74	78	73	76	80	75	78	82
315	4	72	75	78	74	77	80	76	79	83	78	81	85

CONTINUED

Table 2.—Continued

Azi- muth	A ₁ depth	Upper 25% slope			Upper 25-50% slope			Lower 50-75% slope			Lower 75-100% slope		
		Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave
SLOPE GRADIENT = 0.10													
PRECIPITATION = 43													
0	1	67	70	73	69	72	75	71	74	77	73	76	79
0	2	70	72	76	72	74	78	74	76	80	76	79	82
0	3	73	75	79	75	77	81	77	79	83	79	81	85
0	4	75	78	82	77	80	84	80	82	86	82	84	88
45	1	67	70	74	69	72	76	71	74	78	73	76	80
45	2	70	73	77	72	75	79	74	77	81	76	79	83
45	3	73	76	79	75	78	81	77	80	83	79	82	85
45	4	76	79	82	78	81	84	80	83	86	82	85	88
90	1	67	70	74	69	72	76	71	74	78	73	76	80
90	2	70	73	77	72	75	79	74	77	81	76	79	83
90	3	73	76	80	75	78	82	77	80	84	79	82	86
90	4	76	79	82	78	81	84	80	83	86	82	85	88
135	1	67	70	73	69	72	75	71	74	77	73	76	80
135	2	70	73	76	72	75	78	74	77	80	76	79	82
135	3	73	76	79	75	78	81	77	80	83	79	82	85
135	4	76	79	82	78	81	84	80	83	86	82	85	88
180	1	67	69	73	69	71	75	71	73	77	73	75	79
180	2	69	72	76	71	74	78	73	76	80	76	78	82
180	3	72	75	79	74	77	81	76	79	83	78	81	85
180	4	75	78	82	77	80	84	79	82	86	81	84	88
225	1	66	69	72	68	71	74	70	73	77	72	75	79
225	2	69	72	75	71	74	77	73	76	79	75	78	81
225	3	72	75	78	74	77	80	76	79	82	78	81	84
225	4	75	78	81	77	80	83	79	82	85	81	84	87
270	1	66	69	72	68	71	74	70	73	76	72	75	78
270	2	69	72	75	71	74	77	73	76	79	75	78	81
270	3	72	75	78	74	77	80	76	79	82	78	81	84
270	4	75	77	81	77	79	83	79	81	85	81	83	87
315	1	66	69	73	68	71	75	70	73	77	72	75	79
315	2	69	72	76	71	74	78	73	76	80	75	78	82
315	3	72	75	78	74	77	80	76	79	82	78	81	84
315	4	75	78	81	77	80	83	79	82	85	81	84	87

CONTINUED

Table 2.—Continued

Azi- muth	A ₁ depth	Upper 25% slope			Upper 25-50% slope			Lower 50-75% slope			Lower 75-100% slope		
		Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave
SLOPE GRADIENT = 0.10													
PRECIPITATION = 44													
0	1	70	72	76	72	74	78	74	76	80	76	78	82
0	2	73	75	79	75	77	81	77	79	83	79	81	85
0	3	75	78	82	77	80	84	79	82	86	81	84	88
0	4	78	81	85	80	83	87	82	85	89	84	87	91
45	1	70	73	76	72	75	78	74	77	81	76	79	83
45	2	73	76	79	75	78	81	77	80	83	79	82	85
45	3	76	79	82	78	81	84	80	83	86	82	85	88
45	4	79	82	85	81	84	87	83	86	89	85	88	91
90	1	70	73	77	72	75	79	74	77	81	76	79	83
90	2	73	76	79	75	78	82	77	80	84	79	82	86
90	3	76	79	82	78	81	84	80	83	86	82	85	88
90	4	79	82	85	81	84	87	83	86	89	85	88	91
135	1	70	73	76	72	75	78	74	77	80	76	79	82
135	2	73	76	79	75	78	81	77	80	83	79	82	85
135	3	76	78	82	78	81	84	80	83	86	82	85	88
135	4	79	81	85	81	83	87	83	85	89	85	87	91
180	1	69	72	76	71	74	78	73	76	80	75	78	82
180	2	72	75	79	74	77	81	76	79	83	78	81	85
180	3	75	78	82	77	80	84	79	82	86	81	84	88
180	4	78	81	84	80	83	86	82	85	89	84	87	91
225	1	69	72	75	71	74	77	73	76	79	75	78	81
225	2	72	75	78	74	77	80	76	79	82	78	81	84
225	3	75	78	81	77	80	83	79	82	85	81	84	87
225	4	78	80	84	80	82	86	82	84	88	84	86	90
270	1	69	72	75	71	74	77	73	76	79	75	78	81
270	2	72	74	78	74	77	80	76	79	82	78	81	84
270	3	75	77	81	77	79	83	79	81	85	81	83	87
270	4	78	80	84	80	82	86	82	84	88	84	86	90
315	1	69	72	75	71	74	78	73	76	80	75	78	82
315	2	72	75	78	74	77	80	76	79	82	78	81	84
315	3	75	78	81	77	80	83	79	82	85	81	84	87
315	4	78	81	84	80	83	86	82	85	88	84	87	90

CONTINUED

Table 2.—Continued

Azi- muth	A ₁ depth	Upper 25% slope			Upper 25-50% slope			Lower 50-75% slope			Lower 75-100% slope		
		Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave
SLOPE GRADIENT = 0.30													
0	1	57	59	63	59	61	65	61	63	67	63	65	69
0	2	59	62	66	61	64	68	64	66	70	66	68	72
0	3	62	65	69	64	67	71	66	69	73	68	71	75
0	4	65	68	72	67	70	74	69	72	76	71	74	78
45	1	58	61	64	60	63	66	62	65	68	64	67	70
45	2	61	64	67	63	66	69	65	68	71	67	70	73
45	3	64	67	70	66	69	72	68	71	74	70	73	76
45	4	67	69	73	69	71	75	71	73	77	73	75	79
90	1	58	61	65	60	63	67	62	65	69	64	67	71
90	2	61	64	68	63	66	70	65	68	72	67	70	74
90	3	64	67	70	66	69	73	68	71	75	70	73	77
90	4	67	70	73	69	72	75	71	74	77	73	76	79
135	1	57	60	64	59	62	66	62	64	68	64	66	70
135	2	60	63	67	62	65	69	64	67	71	66	69	73
135	3	63	66	70	65	68	72	67	70	74	69	72	76
135	4	66	69	73	68	71	75	70	73	77	72	75	79
180	1	56	59	62	58	61	64	60	63	66	62	65	68
180	2	59	62	65	61	64	67	63	66	69	65	68	71
180	3	62	64	68	64	66	70	66	69	72	68	71	74
180	4	65	67	71	67	69	73	69	71	75	71	73	77
225	1	55	57	61	57	59	63	59	61	65	61	63	67
225	2	57	60	64	59	62	66	61	64	68	63	66	70
225	3	60	63	67	62	65	69	64	67	71	66	69	73
225	4	63	66	70	65	68	72	67	70	74	69	72	76
270	1	54	57	61	56	59	63	58	61	65	60	63	67
270	2	57	60	63	59	62	65	61	64	67	63	66	69
270	3	60	63	66	62	65	68	64	67	70	66	69	72
270	4	63	66	69	65	68	71	67	70	73	69	72	75
315	1	55	58	61	57	60	63	59	62	65	61	64	67
315	2	58	61	64	60	63	66	62	65	68	64	67	70
315	3	61	64	67	63	66	69	65	68	71	67	70	73
315	4	64	66	70	66	68	72	68	71	74	70	73	76

CONTINUED

Table 2.—Continued

Azi- muth	A ₁ depth	Upper 25% slope			Upper 25-50% slope			Lower 50-75% slope			Lower 75-100% slope		
		Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave
SLOPE GRADIENT = 0.30													
PRECIPITATION = 41													
0	1	59	62	66	61	64	68	63	66	70	65	68	72
0	2	62	65	69	64	67	71	66	69	73	68	71	75
0	3	65	68	72	67	70	74	69	72	76	71	74	78
0	4	68	71	75	70	73	77	72	75	79	74	77	81
45	1	61	64	67	63	66	69	65	68	71	67	70	73
45	2	64	66	70	66	68	72	68	71	74	70	73	76
45	3	67	69	73	69	71	75	71	73	77	73	75	79
45	4	70	72	76	72	74	78	74	76	80	76	78	82
90	1	61	64	68	63	66	70	65	68	72	67	70	74
90	2	64	67	70	66	69	72	68	71	74	70	73	77
90	3	67	70	73	69	72	75	71	74	77	73	76	79
90	4	70	73	76	72	75	78	74	77	80	76	79	82
135	1	60	63	67	62	65	69	64	67	71	66	69	73
135	2	63	66	70	65	68	72	67	70	74	69	72	76
135	3	66	69	73	68	71	75	70	73	77	72	75	79
135	4	69	72	75	71	74	77	73	76	79	75	78	81
180	1	59	62	65	61	64	67	63	66	69	65	68	71
180	2	62	64	68	64	66	70	66	68	72	68	70	74
180	3	65	67	71	67	69	73	69	71	75	71	73	77
180	4	67	70	74	69	72	76	71	74	78	74	76	80
225	1	57	60	64	59	62	66	61	64	68	63	66	70
225	2	60	63	67	62	65	69	64	67	71	66	69	73
225	3	63	66	70	65	68	72	67	70	74	69	72	76
225	4	66	69	72	68	71	74	70	73	76	72	75	79
270	1	57	60	63	59	62	65	61	64	67	63	66	69
270	2	60	63	66	62	65	68	64	67	70	66	69	72
270	3	63	66	69	65	68	71	67	70	73	69	72	75
270	4	66	68	72	68	71	74	70	73	76	72	75	78
315	1	58	61	64	60	63	66	62	65	68	64	67	70
315	2	61	64	67	63	66	69	65	68	71	67	70	73
315	3	64	66	70	66	68	72	68	70	74	70	72	76
315	4	67	69	73	69	71	75	71	73	77	73	75	79

CONTINUED

Table 2.—Continued

Azi- muth	A ₁ depth	Upper 25% slope			Upper 25-50% slope			Lower 50-75% slope			Lower 75-100% slope																
		Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave														
SLOPE GRADIENT = 0.30														PRECIPITATION = 42													
0	1	62	65	69	64	67	71	66	69	73	68	71	75														
0	2	65	68	72	67	70	74	69	72	76	71	74	78														
0	3	68	71	74	70	73	76	72	75	79	74	77	81														
0	4	71	74	77	73	76	79	75	78	81	77	80	83														
45	1	64	66	70	66	68	72	68	70	74	70	72	76														
45	2	67	69	73	69	71	75	71	73	77	73	75	79														
45	3	69	72	76	71	74	78	74	76	80	76	78	82														
45	4	72	75	79	74	77	81	76	79	83	78	81	85														
90	1	64	67	70	66	69	72	68	71	74	70	73	76														
90	2	67	70	73	69	72	75	71	74	77	73	76	79														
90	3	70	73	76	72	75	78	74	77	80	76	79	82														
90	4	73	76	79	75	78	81	77	80	83	79	82	85														
135	1	63	66	70	65	68	72	67	70	74	69	72	76														
135	2	66	69	72	68	71	74	70	73	77	72	75	79														
135	3	69	72	75	71	74	77	73	76	79	75	78	81														
135	4	72	75	78	74	77	80	76	79	82	78	81	84														
180	1	62	64	68	64	66	70	66	68	72	68	70	74														
180	2	65	67	71	67	69	73	69	71	75	71	73	77														
180	3	67	70	74	69	72	76	71	74	78	73	76	80														
180	4	70	73	77	72	75	79	74	77	81	76	79	83														
225	1	60	63	67	62	65	69	64	67	71	66	69	73														
225	2	63	66	70	65	68	72	67	70	74	69	72	76														
225	3	66	69	72	68	71	74	70	73	76	72	75	78														
225	4	69	72	75	71	74	77	73	76	79	75	78	81														
270	1	60	63	66	62	65	68	64	67	70	66	69	72														
270	2	63	66	69	65	68	71	67	70	73	69	72	75														
270	3	66	68	72	68	70	74	70	72	76	72	75	78														
270	4	69	71	75	71	73	77	73	75	79	75	77	81														
315	1	61	64	67	63	66	69	65	68	71	67	70	73														
315	2	64	66	70	66	68	72	68	70	74	70	72	76														
315	3	67	69	73	69	71	75	71	73	77	73	75	79														
315	4	69	72	76	71	74	78	73	76	80	75	78	82														

CONTINUED

Table 2.—Continued

Azi- muth	A ₁ depth	Upper 25% slope			Upper 25-50% slope			Lower 50-75% slope			Lower 75-100% slope																
		Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave														
SLOPE GRADIENT = 0.30														PRECIPITATION = 43													
0	1	65	68	72	67	70	74	69	72	76	71	74	78														
0	2	68	71	74	70	73	76	72	75	78	74	77	80														
0	3	71	74	77	73	76	79	75	78	81	77	80	83														
0	4	74	77	80	76	79	82	78	81	84	80	83	86														
45	1	67	69	73	69	71	75	71	73	77	73	75	79														
45	2	69	72	76	71	74	78	73	76	80	75	78	82														
45	3	72	75	79	74	77	81	76	79	83	78	81	85														
45	4	75	78	82	77	80	84	79	82	86	81	84	88														
90	1	67	70	73	69	72	75	71	74	77	73	76	79														
90	2	70	73	76	72	75	78	74	77	80	76	79	82														
90	3	73	75	79	75	77	81	77	80	83	79	82	85														
90	4	76	78	82	78	80	84	80	82	86	82	84	88														
135	1	66	69	72	68	71	74	70	73	76	72	75	78														
135	2	69	72	75	71	74	77	73	76	79	75	78	81														
135	3	72	75	78	74	77	80	76	79	82	78	81	84														
135	4	75	78	81	77	80	83	79	82	85	81	84	87														
180	1	64	67	71	66	69	73	69	71	75	71	73	77														
180	2	67	70	74	69	72	76	71	74	78	73	76	80														
180	3	70	73	77	72	75	79	74	77	81	76	79	83														
180	4	73	76	80	75	78	82	77	80	84	79	82	86														
225	1	63	66	69	65	68	72	67	70	74	69	72	76														
225	2	66	69	72	68	71	74	70	73	76	72	75	78														
225	3	69	72	75	71	74	77	73	76	79	75	78	81														
225	4	72	75	78	74	77	80	76	79	82	78	81	84														
270	1	63	66	69	65	68	71	67	70	73	69	72	75														
270	2	66	68	72	68	70	74	70	72	76	72	74	78														
270	3	69	71	75	71	73	77	73	75	79	75	77	81														
270	4	71	74	78	73	76	80	75	78	82	77	80	84														
315	1	64	66	70	66	68	72	68	70	74	70	72	76														
315	2	66	69	73	69	71	75	71	73	77	73	75	79														
315	3	69	72	76	71	74	78	73	76	80	75	78	82														
315	4	72	75	79	74	77	81	76	79	83	78	81	85														

CONTINUED

Table 2.—Continued

Azi- muth	A ₁ depth	Upper 25% slope			Upper 25-50% slope			Lower 50-75% slope			Lower 75-100% slope		
		Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave
SLOPE GRADIENT = 0.30													
0	1	68	71	74	70	73	76	72	75	78	74	77	80
0	2	71	74	77	73	76	79	75	78	81	77	80	83
0	3	74	77	80	76	79	82	78	81	84	80	83	86
0	4	77	79	83	79	81	85	81	84	87	83	86	89
PRECIPITATION = 44													
45	1	69	72	76	71	74	78	73	76	80	75	78	82
45	2	72	75	79	74	77	81	76	79	83	78	81	85
45	3	75	78	82	77	80	84	79	82	86	81	84	88
45	4	78	81	84	80	83	86	82	85	88	84	87	91
90	1	70	73	76	72	75	78	74	77	80	76	79	82
90	2	73	75	79	75	77	81	77	79	83	79	81	85
90	3	76	78	82	78	80	84	80	82	86	82	84	88
90	4	78	81	85	80	83	87	82	85	89	85	87	91
135	1	69	72	75	71	74	77	73	76	79	75	78	81
135	2	72	75	78	74	77	80	76	79	82	78	81	84
135	3	75	77	81	77	79	83	79	82	85	81	84	87
135	4	78	80	84	80	82	86	82	84	88	84	86	90
180	1	67	70	74	69	72	76	71	74	78	73	76	80
180	2	70	73	77	72	75	79	74	77	81	76	79	83
180	3	73	76	80	75	78	82	77	80	84	79	82	86
180	4	76	79	82	78	81	84	80	83	86	82	85	88
225	1	66	69	72	68	71	74	70	73	76	72	75	78
225	2	69	72	75	71	74	77	73	76	79	75	78	81
225	3	72	75	78	74	77	80	76	79	82	78	81	84
225	4	75	77	81	77	79	83	79	81	85	81	83	87
270	1	66	68	72	68	70	74	70	72	76	72	74	78
270	2	68	71	75	71	73	77	73	75	79	75	77	81
270	3	71	74	78	73	76	80	75	78	82	77	80	84
270	4	74	77	81	76	79	83	78	81	85	80	83	87
315	1	66	69	73	68	71	75	70	73	77	73	75	79
315	2	69	72	76	71	74	78	73	76	80	75	78	82
315	3	72	75	79	74	77	81	76	79	83	78	81	85
315	4	75	78	82	77	80	84	79	82	86	81	84	88

CONTINUED

Table 2.—Continued

Azi- muth	A ₁ depth	Upper 25% slope			Upper 25-50% slope			Lower 50-75% slope			Lower 75-100% slope		
		Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave
SLOPE GRADIENT = 0.50													
PRECIPITATION = 40													
0	1	55	58	61	57	60	63	59	62	65	61	64	67
0	2	58	61	64	60	63	66	62	65	68	64	67	70
0	3	61	64	67	63	66	69	65	68	71	67	70	73
0	4	64	66	70	66	68	72	68	70	74	70	72	76
45	1	57	60	64	59	62	66	61	64	68	63	66	70
45	2	60	63	67	62	65	69	64	67	71	66	69	73
45	3	63	66	69	65	68	71	67	70	73	69	72	75
45	4	66	69	72	68	71	74	70	73	76	72	75	78
90	1	58	61	64	60	63	66	62	65	68	64	67	70
90	2	61	64	67	63	66	69	65	68	71	67	70	73
90	3	64	66	70	66	68	72	68	70	74	70	72	76
90	4	67	69	73	69	71	75	71	73	77	73	75	79
135	1	56	59	63	58	61	65	60	63	67	63	65	69
135	2	59	62	66	61	64	68	63	66	70	65	68	72
135	3	62	65	69	64	67	71	66	69	73	68	71	75
135	4	65	68	72	67	70	74	69	72	76	71	74	78
180	1	54	57	60	56	59	62	58	61	64	60	63	66
180	2	57	59	63	59	62	65	61	64	67	63	66	69
180	3	60	62	66	62	64	68	64	66	70	66	68	72
180	4	63	65	69	65	67	71	67	69	73	69	71	75
225	1	52	54	58	54	56	60	56	58	62	58	60	64
225	2	54	57	61	56	59	63	58	61	65	60	63	67
225	3	57	60	64	59	62	66	61	64	68	63	66	70
225	4	60	63	67	62	65	69	64	67	71	66	69	73
270	1	51	54	57	53	56	59	55	58	61	57	60	63
270	2	54	57	60	56	59	62	58	61	64	60	63	66
270	3	57	59	63	59	62	65	61	64	67	63	66	69
270	4	60	62	66	62	64	68	64	66	70	66	68	72
315	1	52	55	59	54	57	61	56	59	63	58	61	65
315	2	55	58	62	57	60	64	59	62	66	61	64	68
315	3	58	61	65	60	63	67	62	65	69	64	67	71
315	4	61	64	67	63	66	69	65	68	71	67	70	73

CONTINUED

Table 2.—Continued

Azi- muth	A ₁ depth	Upper 25% slope			Upper 25-50% slope			Lower 50-75% slope			Lower 75-100% slope		
		Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave
SLOPE GRADIENT = 0.50													
0	1	58	61	64	60	63	66	62	65	68	64	67	70
0	2	61	63	67	63	66	69	65	68	71	67	70	73
0	3	64	66	70	66	68	72	68	70	74	70	72	76
0	4	67	69	73	69	71	75	71	73	77	73	75	79
45	1	60	63	66	62	65	69	64	67	71	66	69	73
45	2	63	66	69	65	68	71	67	70	73	69	72	75
45	3	66	69	72	68	71	74	70	73	76	72	75	78
45	4	69	72	75	71	74	77	73	76	79	75	78	81
90	1	61	63	67	63	66	69	65	68	71	67	70	73
90	2	64	66	70	66	68	72	68	70	74	70	72	76
90	3	67	69	73	69	71	75	71	73	77	73	75	79
90	4	69	72	76	71	74	78	73	76	80	75	78	82
135	1	59	62	66	61	64	68	63	66	70	65	68	72
135	2	62	65	69	64	67	71	66	69	73	68	71	75
135	3	65	68	71	67	70	74	69	72	76	71	74	78
135	4	68	71	74	70	73	76	72	75	78	74	77	80
180	1	57	59	63	59	61	65	61	64	67	63	66	69
180	2	60	62	66	62	64	68	64	66	70	66	68	72
180	3	62	65	69	65	67	71	67	69	73	69	71	75
180	4	65	68	72	67	70	74	69	72	76	71	74	78
225	1	54	57	61	56	59	63	58	61	65	60	63	67
225	2	57	60	64	59	62	66	61	64	68	63	66	70
225	3	60	63	67	62	65	69	64	67	71	66	69	73
225	4	63	66	69	65	68	71	67	70	74	69	72	76
270	1	54	57	60	56	59	62	58	61	64	60	63	66
270	2	57	59	63	59	61	65	61	63	67	63	66	69
270	3	60	62	66	62	64	68	64	66	70	66	68	72
270	4	62	65	69	64	67	71	67	69	73	69	71	75
315	1	55	58	62	57	60	64	59	62	66	61	64	68
315	2	58	61	64	60	63	67	62	65	69	64	67	71
315	3	61	64	67	63	66	69	65	68	71	67	70	73
315	4	64	67	70	66	69	72	68	71	74	70	73	76

CONTINUED

Table 2.—Continued

Azi- muth	A ₁ depth	Upper 25% slope			Upper 25-50% slope			Lower 50-75% slope			Lower 75-100% slope																
		Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave														
SLOPE GRADIENT = 0.50														PRECIPITATION = 42													
0	1	61	63	67	63	65	69	65	67	71	67	70	73														
0	2	64	66	70	66	68	72	68	70	74	70	72	76														
0	3	66	69	73	68	71	75	71	73	77	73	75	79														
0	4	69	72	76	71	74	78	73	76	80	75	78	82														
45	1	63	66	69	65	68	71	67	70	73	69	72	75														
45	2	66	69	72	68	71	74	70	73	76	72	75	78														
45	3	69	72	75	71	74	77	73	76	79	75	78	81														
45	4	72	74	78	74	76	80	76	78	82	78	80	84														
90	1	64	66	70	66	68	72	68	70	74	70	72	76														
90	2	66	69	73	68	71	75	71	73	77	73	75	79														
90	3	69	72	76	71	74	78	73	76	80	75	78	82														
90	4	72	75	79	74	77	81	76	79	83	78	81	85														
135	1	62	65	69	64	67	71	66	69	73	68	71	75														
135	2	65	68	71	67	70	73	69	72	75	71	74	78														
135	3	68	71	74	70	73	76	72	75	78	74	77	80														
135	4	71	74	77	73	76	79	75	78	81	77	80	83														
180	1	60	62	66	62	64	68	64	66	70	66	68	72														
180	2	62	65	69	64	67	71	66	69	73	69	71	75														
180	3	65	68	72	67	70	74	69	72	76	71	74	78														
180	4	68	71	75	70	73	77	72	75	79	74	77	81														
225	1	57	60	64	59	62	66	61	64	68	63	66	70														
225	2	60	63	67	62	65	69	64	67	71	66	69	73														
225	3	63	66	69	65	68	71	67	70	73	69	72	75														
225	4	66	69	72	68	71	74	70	73	76	72	75	78														
270	1	57	59	63	59	61	65	61	63	67	63	65	69														
270	2	60	62	66	62	64	68	64	66	70	66	68	72														
270	3	62	65	69	64	67	71	66	69	73	68	71	75														
270	4	65	68	72	67	70	74	69	72	76	71	74	78														
315	1	58	61	64	60	63	66	62	65	68	64	67	71														
315	2	61	64	67	63	66	69	65	68	71	67	70	73														
315	3	64	67	70	66	69	72	68	71	74	70	73	76														
315	4	67	70	73	69	72	75	71	74	77	73	76	79														

CONTINUED

Table 2.—Continued

Azi- muth	A ₁ depth	Upper 25% slope			Upper 25-50% slope			Lower 50-75% slope			Lower 75-100% slope		
		Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave
SLOPE GRADIENT = 0.50													
PRECIPITATION = 43													
0	1	64	66	70	66	68	72	68	70	74	70	72	76
0	2	66	69	73	68	71	75	70	73	77	72	75	79
0	3	69	72	76	71	74	78	73	76	80	75	78	82
0	4	72	75	79	74	77	81	76	79	83	78	81	85
45	1	66	69	72	68	71	74	70	73	76	72	75	78
45	2	69	71	75	71	74	77	73	76	79	75	78	81
45	3	72	74	78	74	76	80	76	78	82	78	80	84
45	4	75	77	81	77	79	83	79	81	85	81	83	87
90	1	66	69	73	68	71	75	70	73	77	72	75	79
90	2	69	72	76	71	74	78	73	76	80	75	78	82
90	3	72	75	79	74	77	81	76	79	83	78	81	85
90	4	75	78	82	77	80	84	79	82	86	81	84	88
135	1	65	68	71	67	70	73	69	72	75	71	74	77
135	2	68	71	74	70	73	76	72	75	78	74	77	80
135	3	71	74	77	73	76	79	75	78	81	77	80	83
135	4	74	76	80	76	79	82	78	81	84	80	83	86
180	1	62	65	69	64	67	71	66	69	73	68	71	75
180	2	65	68	72	67	70	74	69	72	76	71	74	78
180	3	68	71	75	70	73	77	72	75	79	74	77	81
180	4	71	74	77	73	76	79	75	78	82	77	80	84
225	1	60	63	67	62	65	69	64	67	71	66	69	73
225	2	63	66	69	65	68	71	67	70	73	69	72	75
225	3	66	69	72	68	71	74	70	73	76	72	75	78
225	4	69	72	75	71	74	77	73	76	79	75	78	81
270	1	60	62	66	62	64	68	64	66	70	66	68	72
270	2	62	65	69	64	67	71	66	69	73	68	71	75
270	3	65	68	72	67	70	74	69	72	76	71	74	78
270	4	68	71	75	70	73	77	72	75	79	74	77	81
315	1	61	64	67	63	66	69	65	68	71	67	70	73
315	2	64	67	70	66	69	72	68	71	74	70	73	76
315	3	67	69	73	69	72	75	71	74	77	73	76	79
315	4	70	72	76	72	74	78	74	76	80	76	78	82

CONTINUED

Table 2.—Continued

Azi- muth	A ₁ depth	Upper 25% slope			Upper 25-50% slope			Lower 50-75% slope			Lower 75-100% slope		
		Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave	Con- vex	Lin- ear	Con- cave
SLOPE GRADIENT = 0.50													
0	1	66	69	73	68	71	75	70	73	77	72	75	79
0	2	69	72	76	71	74	78	73	76	80	75	78	82
0	3	72	75	79	74	77	81	76	79	83	78	81	85
0	4	75	78	81	77	80	83	79	82	86	81	84	88
45	1	69	71	75	71	73	77	73	75	79	75	78	81
45	2	72	74	78	74	76	80	76	78	82	78	80	84
45	3	74	77	81	76	79	83	79	81	85	81	83	87
45	4	77	80	84	79	82	86	81	84	88	83	86	90
90	1	69	72	76	71	74	78	73	76	80	75	78	82
90	2	72	75	79	74	77	81	76	79	83	78	81	85
90	3	75	78	81	77	80	83	79	82	86	81	84	88
90	4	78	81	84	80	83	86	82	85	88	84	87	90
135	1	68	71	74	70	73	76	72	75	78	74	77	80
135	2	71	74	77	73	76	79	75	78	81	77	80	83
135	3	74	76	80	76	78	82	78	80	84	80	83	86
135	4	77	79	83	79	81	85	81	83	87	83	85	89
180	1	65	68	72	67	70	74	69	72	76	71	74	78
180	2	68	71	75	70	73	77	72	75	79	74	77	81
180	3	71	74	77	73	76	79	75	78	81	77	80	83
180	4	74	77	80	76	79	82	78	81	84	80	83	86
225	1	63	66	69	65	68	71	67	70	73	69	72	75
225	2	66	69	72	68	71	74	70	73	76	72	75	78
225	3	69	72	75	71	74	77	73	76	79	75	78	81
225	4	72	74	78	74	76	80	76	78	82	78	81	84
270	1	62	65	69	64	67	71	66	69	73	68	71	75
270	2	65	68	72	67	70	74	69	72	76	71	74	78
270	3	68	71	75	70	73	77	72	75	79	74	77	81
270	4	71	74	77	73	76	79	75	78	81	77	80	83
315	1	64	67	70	66	69	72	68	71	74	70	73	76
315	2	67	69	73	69	71	75	71	73	77	73	76	79
315	3	70	72	76	72	74	78	74	76	80	76	78	82
315	4	72	75	79	74	77	81	77	79	83	79	81	85

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Table 3. Cosine values for plot azimuth having a phase shift angle of 81° (for X_3 in site index prediction equation)

Plot azimuth	X_3 value	Plot azimuth	X_3 value	Plot azimuth	X_3 value	Plot azimuth	X_3 value
N 0	0.1564	E 90	0.9877	S 180	-0.1564	W 270	-0.9877
5	.2419	95	.9703	185	-.2419	275	-.9703
10	.3256	100	.9455	190	-.3256	280	-.9455
15	.4067	105	.9135	195	-.4067	285	-.9135
20	.4848	110	.8746	200	-.4848	290	-.8746
25	.5592	115	.8270	205	-.5592	295	-.8290
30	.6293	120	.7771	210	-.6293	300	-.7771
35	.6947	125	.7193	215	-.6947	305	-.7193
40	.7547	130	.6561	220	-.7547	310	-.6561
NE 45	.8090	SE 135	.5878	SW 225	-.8090	NW 315	-.5878
50	.8572	140	.5150	230	-.8572	320	-.5150
55	.8988	145	.4384	235	-.8988	325	-.4384
60	.9336	150	.3584	240	-.9336	330	-.3584
65	.9613	155	.2756	245	-.9613	335	-.2756
70	.9816	160	.1908	250	-.9816	340	-.1908
75	.9945	165	.1045	255	-.9945	345	-.1045
80	.9998	170	.0175	260	-.9998	350	-.0175
85	.9976	175	-.0698	265	-.9976	355	.0698

List of independent variables tested for predicting oak site quality

1. Latitude—in degrees determined from USGS maps.
2. Longitude—in degrees determined from USGS maps.
3. Azimuth—in degrees.
4. Cosine of azimuth with a phase shift of 45°.
5. Cosine of azimuth with a phase shift of 58° (from Lloyd and Lemmen 1968).
6. Cosine of azimuth with a phase shift of 81°, and adjusted for slope steepness (from Stage 1976) (X_3 in equation).
7. Average slope gradient—general grade of the total slope expressed as percent rise.
8. Plot slope gradient—grade across the plot expressed as percent rise (X_2 in equation).
9. Slope length—total slope length in feet.
10. Distance to ridge—length of slope above the plot to the ridge, in feet.
11. Position on slope—distance between the plot and the ridge expressed as a percentage of total slope length (X_5 in equation).
12. Land form—slope or bench.
13. Slope shape—convex, linear, or concave (b_0 in equation).
14. Basal area—basal area per acre of stems greater than 4.5 inches dbh.
15. Thickness of A_1 horizon—average thickness of the A_1 soil horizon, in inches (X_1 in equation).
16. Thickness of A_3 horizon—average thickness of the A_3 soil horizon, in inches.
17. Thickness of A horizon—combined thickness of A_1 and A_3 soil horizons, in inches.
18. Thickness of B horizon—thickness of all B horizons, in inches.
19. Depth of solum—thickness of A and B horizons, in inches.
20. Total soil depth—depth to bedrock or 6 feet, whichever is shallowest.
21. pH of A_1 horizon—field determination.
22. pH of A_3 horizon—field determination.
23. pH of B horizon—field determination.
24. pH of C horizon—field determination.
25. Percent stones in A_1 —estimated stone content of A_1 soil horizon.
26. Percent stones in A—estimated stone content of $A_1 + A_3$ soil horizons.
27. Percent stones in B—estimated stone content of B soil horizon.
28. Percent stones in C—estimated stone content of C horizon.
29. Reciprocal of stand age— $\frac{1}{\text{Stand Age}}$.
30. Growing season insolation—potential Langleys reaching the plot between May 3 and September 23.
31. Radiation index—ratio of annual radiation to the annual maximum potential solar beam irradiation.
32. Elevation—elevation of the plot above sea level in feet.
33. Rise—rise in elevation from the plot to the highest point within 5 miles, in feet.
34. Annual precipitation—estimated precipitation, in inches (from map, Fig. 4) (X_4 in equation).
35. Square of annual precipitation.
36. Cube of annual precipitation.
37. Reciprocal of annual precipitation.
38. Logarithm of annual precipitation.
39. Square root of annual precipitation.
40. Soil series—Gilpin/Muskingum, Upshur, intergrade (used as dummy variable).
41. Reciprocal of A_1 thickness— $\frac{1}{\text{Thickness of } A_1}$.
42. Reciprocal of A thickness— $\frac{1}{\text{Total thickness of } A_1 + A_3}$.
43. Reciprocal of solum depth— $\frac{1}{\text{Thickness of solum}}$.
44. Reciprocal of total soil depth— $\frac{1}{\text{Soil depth to bedrock or 6 feet}}$.
45. Regional site index—a value of site index calculated from the relationship between site index and aspect plus soil depth for West Virginia.
46. Latitude/longitude interaction—latitude multiplied by longitude.

Headquarters of the Northeastern Forest Experiment Station are in Broomall, Pa. Field laboratories and research units are maintained at:

- Beltsville, Maryland.
 - Berea, Kentucky, in cooperation with Berea College.
 - Burlington, Vermont, in cooperation with the University of Vermont.
 - Delaware, Ohio.
 - Durham, New Hampshire, in cooperation with the University of New Hampshire.
 - Hamden, Connecticut, in cooperation with Yale University.
 - Kingston, Pennsylvania.
 - Morgantown, West Virginia, in cooperation with West Virginia University, Morgantown.
 - Orono, Maine, in cooperation with the University of Maine, Orono.
 - Parsons, West Virginia.
 - Princeton, West Virginia.
 - Syracuse, New York, in cooperation with the State University of New York College of Environmental Sciences and Forestry at Syracuse University, Syracuse.
 - University Park, Pennsylvania.
 - Warren, Pennsylvania.
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