

Site Index Predictions
for Red Oaks and White Oak
in the Boston Mountains of Arkansas

D. L. GRANEY



Summary

Predictive equations based on the relationship of soil and topography to site indices of northern red (*Quercus rubra* L.), black (*Q. velutina* Lam.) and white (*Q. alba* L.) oaks in the Boston Mountains indicate that white oaks should be favored for management on the finer-textured soils and on good south and west slope sites. Both red oaks and white oak could be managed on north- and east-facing sites. Neither species group, however, is recommended for the loamy sandstone soils of the region.

Site index of the red oaks species and white oak was correlated with slope shape-position, aspect, slope gradient, surface soil thickness, sub-

soil texture, and soil group. White oak site index was correlated with slope shape-position, aspect, slope gradient, surface soil texture, and soil group. Separate prediction equations derived for all soils combined and for colluvial plus shale soils accounted for 77 to 79 percent of the variation in red oak site index and 75 to 77 percent of the variation in white oak site index. When tested on independent sets of data, the red oak equations reliably predicted within 5 to 6 feet of measured site index values; white oak equations produced reliable predictions within 3 to 4 feet of measured site index.

Acknowledgement

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Site Index Predictions for Red Oaks and White Oak in the Boston Mountains of Arkansas

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To evaluate investments in silvicultural treatments and to recommend species for management on a given site, land managers in the Boston Mountains need estimates of site productivity for a variety of tree species. A previous study by Graney and Ferguson (1971) produced reliable prediction models relating the site index of shortleaf pine (*Pinus echinata* Mill.) to soil and topographic factors on the major upland soils in the area. Despite problems well summarized by Broadfoot (1969), the soil-site index approach appears to be the most promising one for estimating site potential in areas like the Boston Mountains. This paper reports the relationship of soil and topography to the site indices of northern red (*Quercus rubra* L.), black (*Q. velutina* Lam.), and white (*Q. alba* L.) oaks on major upland soils of the region.

Procedures

Study Area

The Boston Mountains (fig. 1) are the highest, southernmost member of the Ozark Plateaus physiographic province (Fenneman 1938). They form a band 30 to 40 miles wide and 200 miles long extending from central Arkansas westward to east-central Oklahoma.

Elevations range from 1900 to 2500 feet. The plateau is sharply dissected, and most ridges and spurs are generally less than one-half mile wide. Rocks in the area are sedimentary and predominately of Pennsylvanian age; they consist of alternate horizontal beds of shales and resistant sandstones.

Annual precipitation averages 46 to 48 inches in the portion within Arkansas, an area of 2.2 million acres. March, April, and May are the wettest months. Extended summer dry periods are common, and autumn is usually dry. The frost-free period is normally from 180 to 200 days long. The topography was formed by erosion of an uplifted peneplain surface. The tops are flat to gently rolling, and the sides consist of an alternating series of steep simple slopes and gently sloping benches.

Soils common to ridge and upper slope positions are predominantly medium-textured and derived from sandstone residuum (Hartsells, Linker and Mountainburg series); soils common to side slopes are fine-textured and derived from shale residuum (Enders series), and those common to bench positions are typically deep, well-drained, medium-textured soils derived from sandstone and shale colluvium (Nella and Leesburg series).

Field Measurements

Data were collected for 147 red oak plots (northern red oak and black oak) and 138 white oak plots established to represent a range of site conditions common to each species group within the study area. Because height growth patterns and site indices for northern red oak and black oak were similar on all sites and soils, data for each species were combined; they are hereafter referred to as the red oaks.

Study plots were confined to even-aged 40- to 80-year-old stands that were fully stocked and showed no signs of previous heavy cutting or se-

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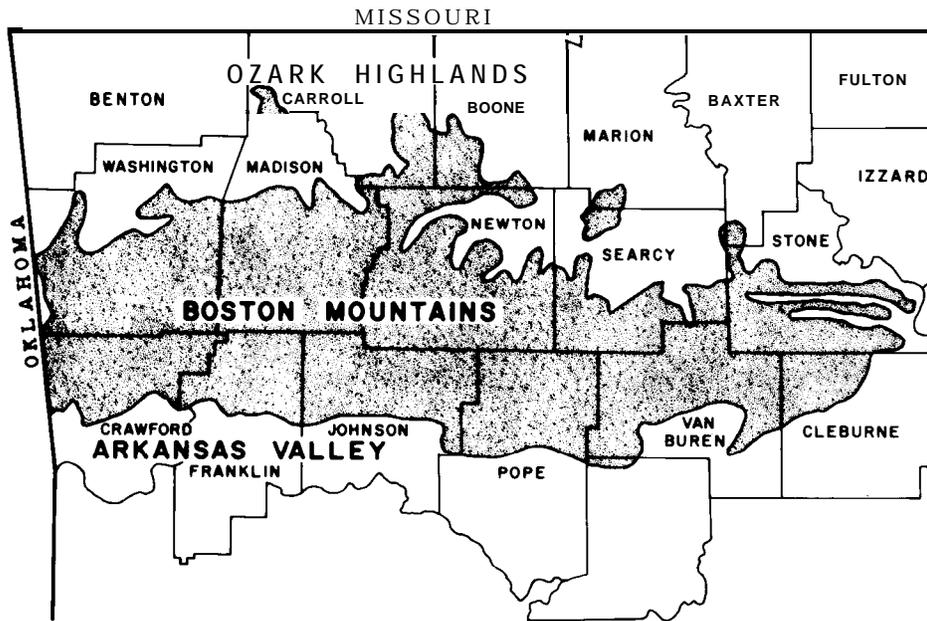


Figure 1.—The Boston Mountains in *Arkansas*.

vere damage from ice or fire. Sample plots varied from one-tenth to one-fifth acre and consisted of three or more dominant or codominant trees grouped as closely as possible to insure uniform soil and topographic conditions.

Tree height and age were obtained from about five (minimum of three) sample trees per plot. On about half of the plots two trees were felled and sectioned at 4 feet intervals to obtain stem analysis data. Site index determinations for these trees were obtained from graphs of height over age. Site index estimates for the remaining trees were obtained by comparing total height and age' with locally derived height growth curves (Graney and Bower 1971). Site index for each plot was then determined by averaging the values obtained for individual sample trees.

On each plot, three soil pits were dug to bed-rock or to a minimum depth of 60 inches. One pit was located at the center of the plot; the others were near the limits of occupancy of the sample trees. No more than one plot was located in an individual stand unless the stand extended over

more than one set of soil or topographic conditions.

All soil profiles were described and classified by Soil Conservation Service soil scientists. Approximately 1 quart of rock-free soil was collected from each major horizon of each soil pit. Also noted were such soil variables as stone content, depth and thickness of the horizons, depth of maximum root penetration, and total soil depth.

Topographic variables determined for each plot were elevation, aspect, slope shape and position, steepness and length, distance from top of slope, township, and range.

Laboratory Measurements

The bulk soil samples were air-dried, rolled, and sieved through a 2-mm-mesh screen. Corresponding horizon samples for the three soil pits in each plot were composited for analyses of pH, particle size distribution, and moisture contents at 1/3 and 15 atmospheres of tension.

Data Analysis

One-fifth of the sample plots for each species-soil group combination were randomly selected and excluded from the original analyses to provide a population on which to test the effectiveness of the derived equations.

Site index was consistently higher for the red

Total age was defined as the age determined from increment cores at breast height plus 2 years for the red oaks and 3 years for white oak. The number of years to be added for each species was determined from tree section data.

oaks than for white oak (fig. 2). Similar site index differences between white oak and various red oak species have been reported for other areas (Doolittle 1958, Olson and Della-Bianca 1959, Hannah 1968b, Watt and Newhouse 1973). Site index for the red oaks was highest on colluvial soils and poorest on sandstone soils; site index for white oak was highest on colluvial and shale soils and lowest on sandstone. Therefore, separate analyses were completed for each species group; two equations were derived for each group—a general equation to predict site index for all soils and a separate equation developed specifically for the productive colluvial plus shale soils.

Of the 147 red oak plots, 118 were used to derive the all-soils equation and 29 served as test plots. The colluvial plus shale soils equation was based on 92 plots and tested on 23 plots. White oak all-soils equations were derived for 112 analysis plots and tested on 26 additional plots. Eighty-eight plots were used to generate the colluvial plus shale soils equations and were tested using 21 plots.

Initially, 35 original soil and topographic site variables plus a series of transformations and two-variable interactions were screened for possible correlations with site index by using the FSCREEN Regression Program described by Frayer and others (1971). The most promising

variable from each species-soil group screening was used to derive the regression equations relating oak site index to the selected variables. The reliability of each prediction equation was determined by comparing the predicted site index data to the data actually measured. The accuracy of each equation was determined by calculating the error of prediction at both the 0.05 and 0.10 probability levels with a modification of Freese's (1960) accuracy test. In the present analysis,

$$E = \sqrt{\frac{\sum_{i=1}^n (x_i - U_i)^2}{\chi^2}} \quad (T)$$

where: E = error of prediction (calculated deviation from the measured value)

χ^2 = the tabular χ^2 value for the selected probability level and n df.

T = the standard normal deviate value at the selected level of probability (0.05 or 0.10).

Results

After original equations were derived for each species and for soil groups, final equations were derived from the entire data sets representing

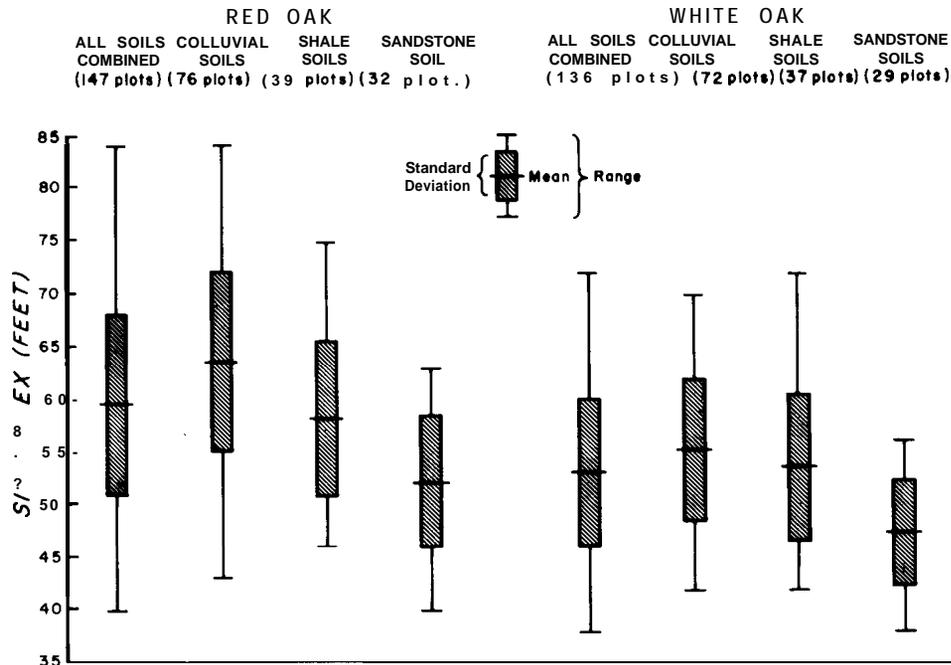


Figure 2.—Site index mean, range, and standard deviation for red oak and white oak on major soil groups of the Boston Mountains of Arkansas.

Table 1.-Coefficient values of the original and final regression equations for predicting red oak and white oak site index (Y) based on soil and topographic variables for the all-soils and colluvial plus shale soil groups.

Independent variable	Red Oak Equations				White Oak Equations			
	All-soils		Colluv. + shale soils		All-soils		Colluv. + shale soils	
	Original model (118 plots)	Final model (147 plots)	Original model (92 plots)	Final model (115 plots)	Original model (112 plots)	Final model (138 plots)	Original model (88 plots)	Final model (109 plots)
Intercept (b ₀)	76.178	76.911	67.421	66.126	49.790	47.959	37.560	37.396
Aspect	2.348	2.393	2.752	2.894	1.732	1.698	1.980	1.990
Slope shape-position	3.503	3.569	3.799	3.867	3.267	3.246	3.365	3.352
Surface soil clay					0.370	0.414	0.368	0.382
Subsoil texture			-0.089	-0.083	—	—	—	—
1/Slope gradient	- 12.997	-11.454	-7.847	-6.873	-9.316	-9.694	-6.479	-7.331
1/Surface soil depth	- 120.821	-117.895	-97.469	-93.007	—	—	—	—
1/Soil group	- 12.560	- 14.224	—	—	- 13.422	- 12.327	—	—
R²	0.79	0.79	0.77	0.77	0.75	0.77	0.73	0.75
Standard error (± feet)	4.29	4.20	4.27	4.17	3.58	3.36	3.62	3.38

Description of independent variables:

Aspect = Cosine of azimuth from northeast

Slope shape-position = coded 1-5 where 1 = flat ridge tops and narrow spur ridge top positions

2 = convex slopes

3 = linear slopes

4 = concave side slopes and mid-bench positions

5 = inner-bench positions

Surface soil clay = percent clay A₁ + A₂ horizons

Subsoil texture = percent silt + clay B₂ horizon

Slope gradient = slope gradient (percent)

Surface soil depth = thickness of A₁ + A₂ horizons (inches)

Soil group = coded separately for each species as: $\frac{\text{(mean site index of soil group)}}{\text{(mean site index of sandstone soils)}}$

each species-soil group combination (table 1). All original equations explained 73 to 79 percent of the variation in red or white oak site index; the standard error of estimate was 4.3 feet or less for each red oak equation and 3.6 feet or less for each white oak equation. Site index predictions with each of the equations were reasonably accurate when tested against the independent set of test plot data (table 2).

Ninety percent of the red oak all-soils test plot predictions fell within 5 feet of measured site index, 96 percent fell within 6 feet, and only one prediction missed the measured value by more than 6 feet. Calculated error at the 0.05 level was ± 5.7 feet; the error at the 0.10 level was ± 5 feet. Thus, the equation reliably predicts within approximately 5 to 6 feet of the measured site index.

Site-index predictions by the red oak colluvial plus shale soils equation were slightly more erratic than those from the all-soils equation, but about 83 percent fell within 5 feet of measured values and all predictions were within 6 feet of test plot site index. Assuming a 1 in 20 chance of error, the colluvial plus shale soils equation will predict within about 6 feet of measured site index and within about 5 feet of measured values nine of ten times (table 2).

Although predictions for white oak appeared more accurate than those for red oak (table 2), there was also less variation in white oak site index than was observed for the red oaks. For the all-soils equation, all predictions fell within 5 feet of measured test plot site index; more than 85 percent of the predictions were within 3 feet of measured values. The calculated error of predictions was 3.8 feet at the 0.05 probability level and 3.4 feet at the 0.10 level.

The white oak colluvial plus shale soils equation also produced reliable predictions of test plot site index. As with the all-soils equation, all predictions fell within 5 feet, and more than 85 percent of the predictions were within 3 feet of measured site index. The equation will predict within 3.4 and 3 feet of measured site index values at the 0.05 and 0.10 probability levels, respectively.

Although shown to produce reasonably accurate site index predictions, the original red and white oak equations were derived from only a portion of the available data. The best estimates of the regression coefficients for each equation should be based upon the entire available data set. Consequently, to obtain the best estimates we completed one additional fitting of the data

Table 2.—Accuracy of red oak and white oak site index prediction equations on test plots.

Soil group equation	Original Analysis				Test Plots							
	Number of plots	SI mean and SD	R ²	Standard error	Number of plots	SI mean and SD	Accuracy of predictions				Maximum deviation	
							Calculated error E(.05)	Calculated error E(.10)	R ²	Within 5 ft		Within 6 ft
ft	ft	%	ft	ft	ft	ft	%	%	%	ft	ft	
All soils	118	60 ± 9	79	± 4.3	29	59 ± 8	RED OAK				7	
							± 5.7	± 5.0	81	90		96
Colluvial + shale soils	92	62 ± 9	78	± 4.3	23	61 ± 8	WHITE OAK				6	
							± 5.9	± 5.2	75	83		100
All soils	112	53 ± 7	75	± 3.6	26	53 ± 7	RED OAK				5	
							± 3.8	± 3.4	86	100		—
Colluvial + shale soils	88	55 ± 7	73	± 3.4	21	54 ± 6	WHITE OAK				5	
							± 3.4	± 3.0	86	100		—

(analysis plus test plots) for each species-soil group combination. Final coefficients in each equation changed only slightly from the original estimates; R^2 values were the same for both original and final red oak equations (table 1). For both species, standard error of estimate was lower in each final equation.

The final colluvial plus shale soil equation for each species was used to calculate trend graphs (figs. 3 and 4) that show relationships between site index and various soil and topographic site variables. For each variable shown, a range of values was inserted into the equation while the other variables were kept constant at their mean values.

Discussion

The final equations not only predict site index accurately but also reveal much about the importance of individual soil and topographic factors in the growth of red and white oaks in the Boston Mountains.

Slope Shape-Position

In this study, slope shape referred to a slope's position or location as well as to its concave, linear, or convex shape. Slope shape was the most influential variable in all equations for each species (figs. 3 and 4). In each equation about 60 percent of the total variation in site index was associated with this combined topographic variable. Similar correlations between slope shape and site index have also been reported for shortleaf pine in Arkansas and Missouri (Graney and Ferguson 1971, 1972), white oak in Indiana (Hannah 1968a) and for black oak in Ohio (Carmean 1967). Bowersox and Ward (1972) have also reported a significant relationship between upland oak site index and a combined slope shape-position variable in the Ridge and Valley region of Pennsylvania.

Differences in soil water availability probably contributed most heavily to observed variations in site index. The sites (Fig. 5) (poorest to best) were (#1) the relatively flat mountain tops and narrow spur ridges, where soils are usually loamy, shallow to medium in depth, and of poor water-holding capacity; (#2) the convex side slope positions typified by upper slopes and outer portions of mountain benches, which normally experience a rapid loss of surface and subsurface water; (#3) simple linear slopes -neither convex or concave; (#4) concave side slopes and all mountain bench positions not included in (#2) and (#5), both of

which receive water supplements from upper slope positions and are normally characterized by deep, medium-textured soils with high water storage capacities; and (#5) inner portions of mountain benches located at the base of steep interbench slopes. The inner-bench positions are strongly concave and are also characterized by very deep medium-textured soils.

Horizontal bedding of rock layers also contributes to the superiority of inner-bench conditions. Subsurface water tends to flow down slope along

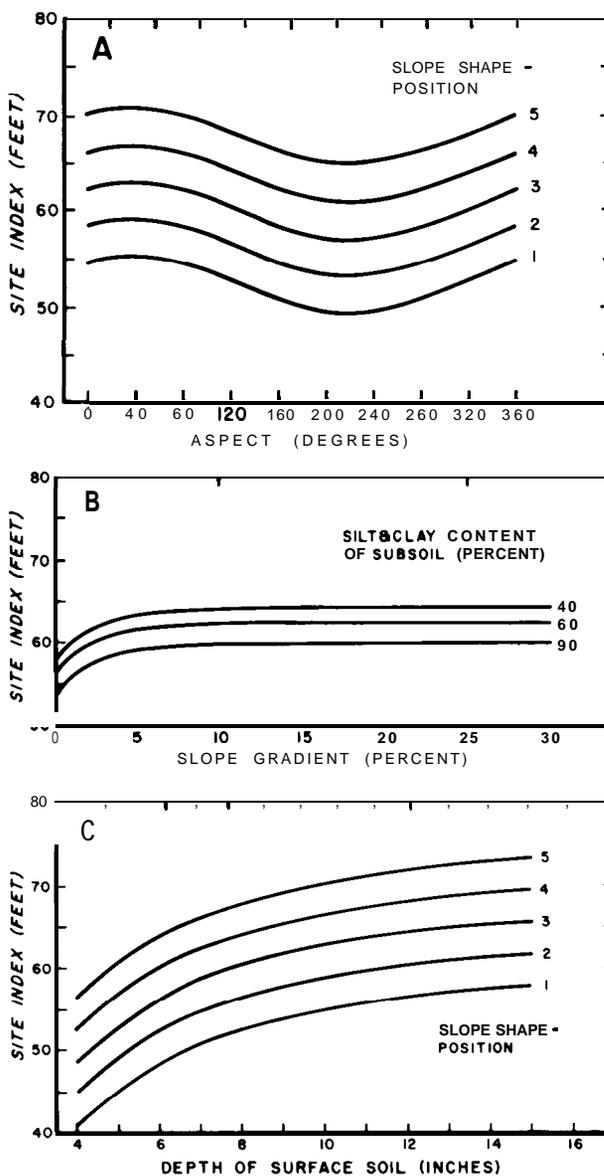


Figure 3.—Relationship between red oak site index and (A) aspect and slope shape-position, (B) slope gradient and silt plus clay content of subsoil and (C) depth of surface soil and slope shape-position.

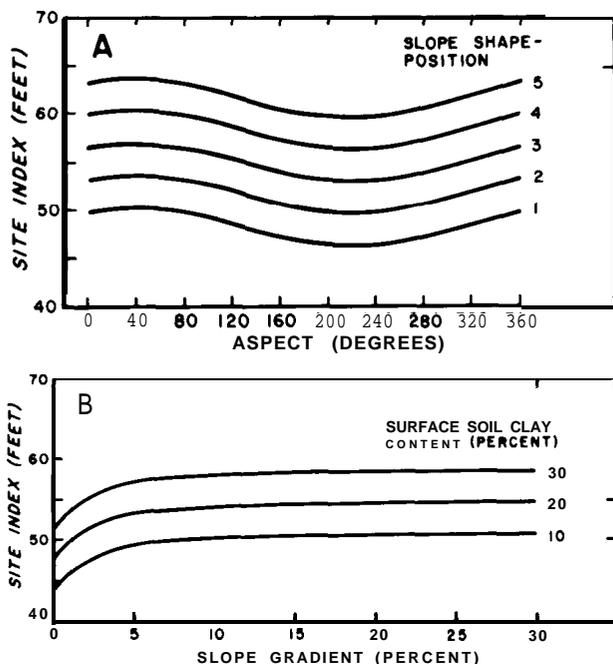


Figure 4.—Relationship between white oak site index and (A) aspect and slope-shape position and (B) slope gradient and surface soil clay content.

the bedrock surface and accumulate at the base of the slope. Such positions would also tend to receive subsurface water for relatively long periods. On wider benches (2 to 4 chains), site index decreases rapidly from the inner one-third to the outer edge of the bench, and could vary by as much as 15 feet. Since deep, colluvial accumulations on bench sites are resting on resistant sandstone layers, soil water could pass through the inner-bench soils to depths beyond effective rooting depths of trees on middle and outer bench positions, then follow rock formations horizontally and occur as "seeps" at another inner-bench position further down slope.

Aspect and Slope Gradient

Aspect has contributed significantly to upland oak site quality in several studies. Northeast-facing slopes are usually associated with good oak site quality and southwest-facing slopes with poor sites. The greater net radiation associated with southwest-facing slopes apparently produces higher temperatures, greater rates of evapotranspiration, and more rapid use of total available soil moisture during the growing season than occur on cool northeast-facing slopes (Carmean 1965, 1967). In areas with high summer rainfall, moisture stresses due to temperature may influence growth more than does soil moisture regime. In

the mountains of West Virginia, Lee and Sypolt (1974) observed that on south-facing slopes lower midday soil temperatures limit absorption of available water while higher canopy temperatures increase the transpiration demand. Vegetation on south-facing slopes might be subjected to daily stresses more severe and of greater duration than those occurring on north-facing slopes; therefore levels of assimilation would be lower on south-facing slopes. Soils on northeast aspects are often deeper and have more organic matter and soil nutrients than comparable soils on southwest-facing slopes. In this study, red oaks were more sensitive to changes in aspect than white oak (figs. 3 and 4). Maximum site index differences between northeast and southwest slopes were about 5 to 6 feet for the red oak species and about 3 to 4 feet for white oak. White oak is often the dominant species on south and west slopes in the study area.

Site index for each species also increased with increasing slope steepness. The effect of slope gradient was most pronounced for slopes ranging from nearly level to about 10 percent, while slopes of more than 10 percent had little influence on site quality. Although slope gradient might indicate differences in soils (the loamy group commonly occurs on nearly level to gently rolling positions), it probably indicates the effect of rapid drainage of the fine-textured Enders soil on sloping sites. On relatively level sites the Enders soils, which have clayey subsoils, tend to drain slowly, and aeration problems might occur during wet spring months.

Depth of Surface Soil

Red oak site index was strongly correlated with surface soil depth (A1 + A2 horizons). Site in-

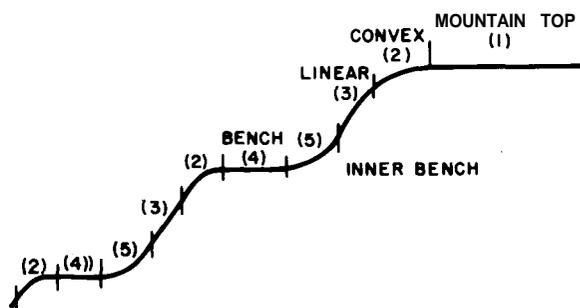


Figure 5.—Slope shape-position classification for typical topographic features of the Boston Mountains; (1) flat ridge tops and narrow spur ridgetop positions, (2) convex slopes, (3) linear slopes, (4) concave side slopes and mid-bench positions, (5) inner-bench positions.

dex increased rapidly with increasing A horizon thickness up to about 8 inches, then increased more slowly as the horizon became thicker (fig. 3). Coile (1952) has pointed out that soil depth and thickness of the horizons near the surface reflect the quality and quantity of the root environment. Because Boston Mountain surface soils are typically porous, have a granular structure, and contain moderate amounts of organic matter and nutrients, they should provide a favorable environment for root growth and development. When the A horizon is thick, the soil volume is favorable for root growth and ultimately for tree growth. In this study thick A horizons were often associated with the deep colluvial soils occurring on the lower slope positions. Therefore, the surface soil depth variable could be associated with differences in soil group productivities (fig. 2).

Although surface soil thicknesses were about the same for red and white oak plots, correlations between this variable and white oak site index were weak. Evidently, white oak is less sensitive to the quality of the root environment than red oak and will grow well over a wide range of soil depths and textures.

Surface Soil Clay and Subsoil Texture

White oak site index increased linearly with increasing clay content of the A horizons (fig. 4). Ike and Huppuch (1968) have reported high white oak site quality associated with finer-textured surface soils in the mountains of Georgia. In the Boston Mountains, low surface soil clay contents are generally associated with sandy residual soils, while moderate to high clay contents are usually found in colluvial and shale soils, which were about equal in average white oak productivity.

For red oaks, subsoil textures were correlated with site index only for the colluvial plus shale soils group. Red oak site quality decreased as silt plus clay contents increased (fig. 3), an indication of the superiority of medium-textured colluvial soils. The decreases in red oak site index when silt plus clay content increases show that red oaks are more sensitive to quality and quantity of the root environment than white oak. Roots tend to penetrate more deeply into soils with medium-textured subsoils than into those with predominantly clay subsoils, which have slow internal drainage in the wet spring months and resist root penetration in the dry summer months.

Conclusion

White oak should be favored for management on finer-textured soils and on the better south and west slope sites, while both red oaks and white oak could be managed on north- and east-facing sites. Though white oak site index (base age 50) is commonly lower than red oak on better sites, it maintains a fairly rapid rate of height growth up to and beyond age 80, while red oak height growth declines rapidly after about age 60 (Graney and Bower 1971). Thus, at a rotation age of 80 to 100 years on medium to good sites, white oak could attain about the same or greater height as red oak.

Neither oak species group is recommended for management on the loamy, sandstone soils. Not only is oak productivity low for these soils, but tree form and log quality are also poor. A previous site index study in the Boston Mountains (Graney and Ferguson 1971) has shown that shortleaf pine productivity is relatively high for loamy soils. On these soils, shortleaf pine is recommended for management.

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The relationship of soil and topography to site indices of northern red (*Quercus rubra* L.), black (*Q. velutina* Lam.) and white (*Q. alba* L.) oaks in the Boston Mountains indicates that white oaks should be favored for management on the finer-textured soils and on good south and west slope sites. Both red oaks and white oak could be managed on north- and east-facing sites. Neither species group, however, is recommended for the loamy sandstone soils of the region.

Additional keywords: *Quercus rubra* L., *Q. velutina* Lam., *Q. alba* L., aspect, slope shape, slope gradient.





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