Shortleaf Pine Site-Index Relationships in the Ozark Highlands[1]

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ABSTRACT

By carefully limiting the area of application and the soils included in individual analyses, practical equations were developed for predicting shortleaf pine (*Pinus echinata* Mill.) growth on major soils in the Ozark Highlands. Large pits were dug to adequately classify the soils, and soil properties were determined by standard techniques. Shortleaf pine site index at age 50 was correlated with aspect, slope shape, loss-on-ignition of the A1 and Ap1 horizons, depth to fragipan, and latitude. Regression equations developed for limestone and dolomite soils, sandstone soils, and fragipan soils predicted site indexes within an average of 0.6 m (2 feet) on confirmatory plots.

***Additional Index Words:* *Pinus echinata*, growth, soil-site evaluation.**

LAND MANAGERS in the Ozark Highland Province of Arkansas and Missouri need estimates of site productivity to evaluate investments in pine forestation, but most timber stands there have long records of high-grading, indiscriminant grazing, and wildfires that make existing trees poor indicators of site quality. An indirect method of estimating productivity is required. This paper reports a comprehensive study of the relations of soil and topography to the site index of shortleaf pine (*Pinus echinata* Mill.) on major soils of the Province.

Indirect methods of site estimation based on correlations with measureable soil and topographic characteristics have been developed for various tree species throughout the United States. In previous research (Coile, 1952; Zahner, 1958; Ralston, 1964) soil and topographic features that influence soil moisture and soil aeration have been most closely correlated with shortleaf pine height growth. Although Broadfoot (1969) has pointed out problems in indirect site estimation, the soil-site approach appears to be the most promising for predicting site quality in the area.

STUDY AREA

The Ozark Highlands cover approximately 12 million ha (30 million acres) in southern Missouri, northern Arkansas, and northeastern Oklahoma (Fig. 1). Shortleaf pine's range is

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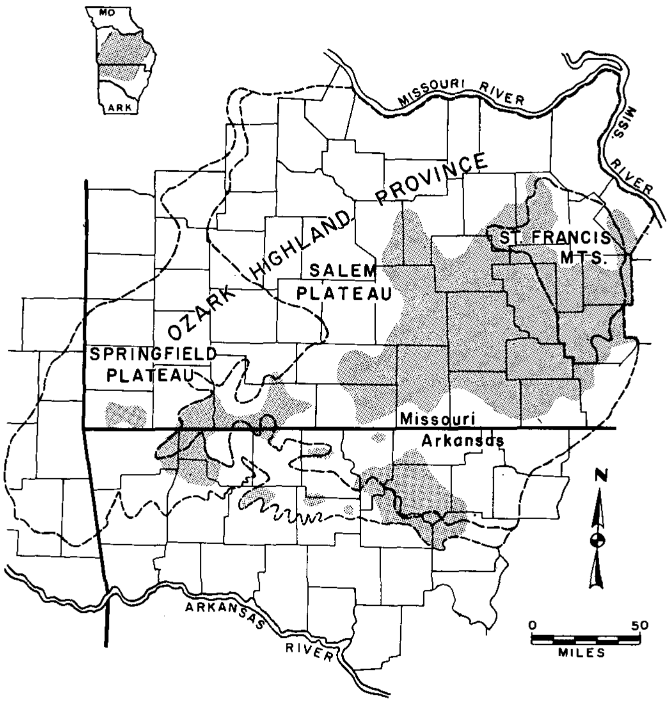

Fig. 1—Range of shortleaf pine in the Ozark Highland Province. Dash line indicates major divisions of the province and shaded areas indicate major concentrations of pine.

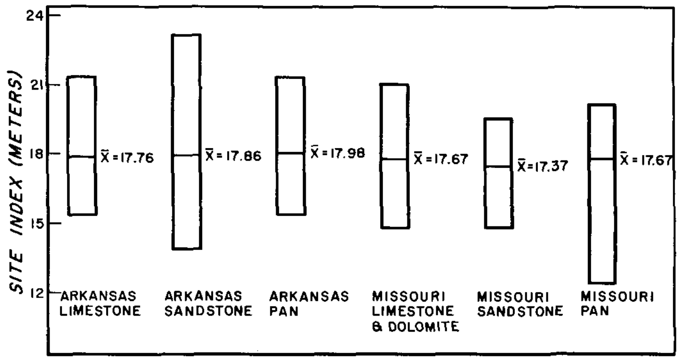

Fig. 2—Shortleaf pine site index for major soil groups.

limited mainly to the southern and eastern portions of the Highlands where it is found occasionally in pure stands but mostly in mixture with hardwoods.

Average annual precipitation ranges from less than 100 cm (40 inches) in the north and west portion of the area to 130 cm (50 inches) in the south and east. April, May, and June are the wettest months. Extended summer droughts are common, and the autumn is usually dry. The average frost-free period ranges from 170 days in the northern to 200 days in the southern portion of the area.

Topography is gently rolling to steep, and elevations range from about 150 m to 460 m (500 to 1,500 feet) above sea level. Soils are derived from essentially horizontally-bedded sandstones and cherty limestones and dolomites. Geologic ages for the parent materials range from Cambrian to Mississippian.

PROCEDURES

Since very large variation in soil properties can lead to inaccuracy in predicting productivity, major soils of the area were divided into three groups: soils of cherty limestone and dolomite origin, soils of sandstone origin, and fragipan soils. Provision was made for separate analyses of each soil group in each State. Prediction equations were developed from data taken on 221 plots and the equations were tested for accuracy on 75 additional plots.

Field

Arkansas cherty limestone soils (Baxter, Clarksville series) were represented by 75 plots; Arkansas sandstone soil (Pineville, Linker, Hartsells, Christian series) by 65 plots; Arkansas fragipan soils (Nixa, Captina series) by 18 plots; Missouri cherty limestone and dolomite soils (Baxter, Clarksville, Macedonia series) by 57 plots; Missouri sandstone soils (Coulstone series) by 46 plots; and Missouri fragipan soils (Lebanon, Nixa, Hobson series) by 35 plots. The range in site index for each of the soil groups is shown in Fig. 2.

Study plots were confined to even-aged 30- to 70-year-old stands of shortleaf pine and pine-hardwood mixtures. Plots ranged from approximately 0.04 to 0.08 ha (1/10 to 1/5 acre) in size with at least three dominant or co-dominant sample trees grouped as closely as possible to insure uniform soil conditions. 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.

Tree age was determined by adding three to the number of rings at breast height. Height of each tree was measured to the nearest foot and converted to meters. Site index, tree height in feet at age 50, for each plot was determined from the mean age and height using curves from USDA Misc. Pub. 50 (1929) and converted to meters.

On each plot, three soil pits were dug with a backhoe to bedrock or to a minimum depth of 1.3 m (50 inches). One pit was at the approximate center of the plot; the other pits were near the limits of occupancy of the sample trees. The pits were large enough for the soil scientist to enter and examine the exposed profile, and they were oriented to provide maximum sunlight on the face being classified.

All soil profiles were described and classified by soil scientists from the Soil Conservation Service or the Forest Service according to defined concepts of the individual soil series in the 7th Approximation (USDA Soil Conservation Service, 1967). Soil samples were collected from each major horizon of each soil pit. Elevation and aspect, slope shape, position, steepness and length, and distance from top of slope were measured or estimated.

Depth to bedrock ranged from less than 0.6 m to more than 1.8 m (2 to 6 feet). Subsoil texture varied from light sandy clay loam to heavy clay.

Laboratory

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 analysis. Portions of the samples were used to determine particle-size distribution, percent loss-on-ignition, pH, and moisture contents at ⅓ and 15 atmospheres (atm.) of tension. Sand, silt, and clay contents were determined by hydrometer after dispersion in 5% sodium metaphosphate (Bouyoucos, 1962). Organic matter content was estimated from loss-on-ignition (650C) following the techniques of the Forest Soils Committee of the Douglas Fir Region (1953). pH of a 1:1 soil-water mixture was determined by glass electrode. Moisture contents at ⅓ and 15 atm were determined by pressure plate and pressure membrane (Richards, 1947, 1948). The difference between the two values was taken as an index of available moisture storage capacity.

Data Analysis

Of the 296 selected plots, 75 with a maximum of 20 from each soil group were randomly selected and excluded from initial analyses to provide a second population on which to test the effectiveness of the derived equations.

In studies of soil-site relations, tree age is sometimes included as an independent variable, and total height is the dependent variable. However, since the possibility of age bias seemed remote in this study, site index—the height of trees at age 50—was chosen as the independent variable.

A series of regressions was computed for each soil series and for soil groups. Of 32 independent variables screened, 19 were correlated with site index for one or more of the single and combined soil groups:

LI = Loss-on-ignition A1 horizon (%)[3]
SS = Slope Shape (1 = Convex, 2 = Linear, 3 = Concave)
Asp 3% + = Aspect — Cos (Azimuth — 40°) Slopes 3% and greater
Asp 10% + = Aspect — Cos (Azimuth — 40°) Slopes 10% and greater
D = Depth to bedrock or Pan (cm)
CH = Distance from top of contributing slope (meters)
S = Slope (%)
pH A = pH A2 Horizon
pH B = pH B2 Horizon
SiClA = Silt + Clay A1 + A2 Horizons (%)
SiClB = Silt + Clay B2 Horizon (%)
ClA = Clay content A1 + A2 Horizons (%)
ClB = Clay content B2 Horizon (%)
T = Township (Coded: 1 = T33N, ..., 19 = T15N)
R = Range (Coded: 1 = R26W, ..., 25 = R2W)
T+R = Township + Range (Township Code + Range Code)
TA = Thickness of A1 + A2 Horizon, (cm)
DB = Depth to B2 Horizon, (cm)
$(TA)^2$ = (Thickness of A1 + A2 Horizons)^2

Multiple regression analyses were then computed for individual soil groups within States and for combinations of similar soil groups in both States.

The statistical model was:

$$Y = b_0 + b_1X_1 + \ldots + b_nX_n$$

where Y = shortleaf pine site index

$X_0, X_1, \ldots X_n$ = independent variables

$b_0, b_1, \ldots b_n$ = coefficients associated with the independent variables.

The data were processed using Program BMD 02R which computes a sequence of multiple linear regression equations in a step-wise manner. At each step, one variable is added to the regression equation and tested at the 5% level. The variable added is the one which makes the greatest reduction in the error sums of squares.

[3] A1 and A2 horizon designations correspond to those defined by the Soil Conservation Service (1962). The A horizons from abandoned field sites (where a plowing history was evident) were described as Ap1 and Ap2 and were comparable in thickness and texture to true A1 and A2 horizons. Therefore, in the text of the paper the A1 or A2 horizon designation will also include Ap1 or Ap2 horizons.

Table 1—Deviations between measured and predicted (using appropriate regression equations) site index

Soils	Total plots	Deviation in meters									
		-1.2	-0.9	-0.6	-0.3	0	+0.3	+0.6	+0.9	+1.2	Avg
Limestone & dolomite soils (Equation [1])	35	0	3	4	5	9	5	6	3	0	0.42
Sandstone soils (Equation [2])	20	0	0	2	3	3	3	3	4	2	0.55
Pan soils (Equation [3])	20	0	2	1	6	3	3	3	1	1	0.46
Total	75	0	5	7	14	15	11	12	8	3	0.46

RESULTS AND DISCUSSION

Equations—Useable equations were derived for individual soil groups and for each State, but the efficiency of these was not markedly superior to that achieved with combined data. For prediction, the most useful equations were those derived for three sets of combined soil groups in both states:

Combined Arkansas and Missouri limestone and dolomite soils (97 plots):

Shortleaf Pine SI = 56.8 + 2.29 (SS) + 2.31 (Asp 3%+) — 0.91 (LI) + 0.31 (T) [1]

$R^2 = 0.63$ Standard error of estimate $S_y.x = 0.89$

Combined Arkansas and Missouri sandstone soil groups (91 plots):

Shortleaf Pine SI = 57.2 + 3.37 (Asp 3%+) + 2.14 (SS) — 0.79 (LI) [2]

$R^2 = 0.49$

Standard error of estimate $S_y.x = 1.30$

Combined Arkansas and Missouri Pan soils (33 plots):

Shortleaf Pine SI = 33.9 + 1.08 (D) + 2.46 (Asp 3%+)

$R^2 = 0.74$ [3]

Standard error of estimate $S_y.x = 0.71$

Predictions with the equations were reasonably accurate on confirmatory plots (Table 1). For the 35 plots on limestone and dolomite soils, all deviations were within ±1 m (3 feet) of measured values, and the mean deviation was less than 0.5 m (1.5 feet). Site indices on confirmatory and analysis plots were quite similar, ranging from 15 to 21 m (approximately 48–70 feet).

On the 20 confirmatory plots on Arkansas and Missouri sandstone soils, most predictions fell within 1 m of actual values; two missed by + 1.2 m (4 feet). Average deviation for the 20 predictions was 0.5 m (1.8 feet). Site index ranges for confirmatory plots were 15 to 21 m (48–69 feet) and 14 to 23 m (45–76 feet) for analysis plots.

Similar results were found for the 20 confirmatory plots on Arkansas and Missouri pan soils. Predicted values generally fell within 1 m of measured values and the average deviation was 0.5 m. Site index for these confirmatory plots ranged from 14 to 21 m (45–69 feet) as compared with 15 to 21 m (48–70 feet) for analysis plots.

Equations [1] and [3] were used to calculate trend graphs (Fig. 3 to 7) that illustrate the relationships between site index and the significant soil and topographic factors. For each figure, values were inserted into the equation for one variable while all other variables in the equation were held constant at their mean values.

The equations could not predict site index if the soil and

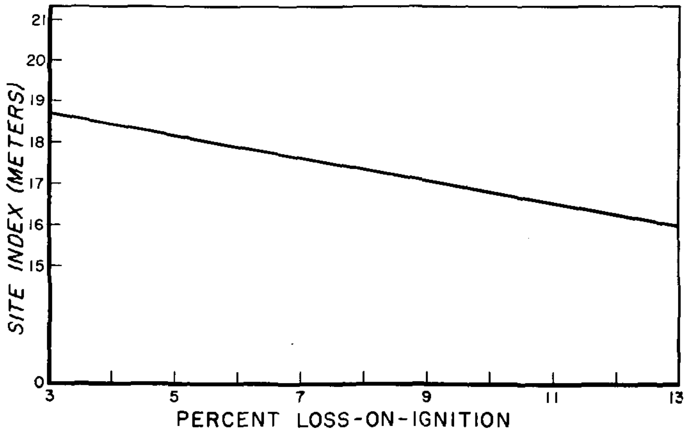

Fig. 3—Relative effect of loss-on-ignition values in A1 horizon on site index (Equation [1]).

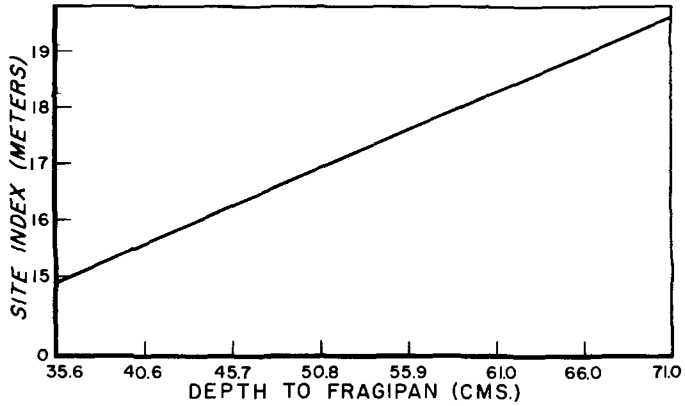

Fig. 4—Changes in site index with changes in depth to fragipan on fragipan soils (Equation [3]).

topographic factors in them were not related to conditions necessary for tree growth. Therefore, some interpretations are proposed concerning the possible biological factors underlying the mathematical relationships observed in this study.

Loss-On-Ignition

Percent loss-on-ignition of the A1 horizon was significant or exhibited high linear correlation with site index in all analyses. Figure 3 (derived from equation [1]) illustrates the negative relationship between loss-on-ignition and shortleaf pine site index. Loss-on-ignition values obtained are considered to approximate organic matter levels for the various sample plots. Ball (1964) investigated loss-on-ignition for estimating organic-matter content and concluded that it was a simple and rapid method and justified more consideration than most standard references recommend. The soils of this study were non-calcareous and the texture classes for A1 horizons were sandy loams or silt loams with clay contents ranging from 7 to 17% for soils derived from sandstones and 13 to 22% for limestone and dolomite soils. Consequently, it was concluded that errors resulting from loss of CO_2 from carbonates or from clay fractions would be minimal and relative.

Within general limits, high organic matter is generally associated with high fertility. But negative correlations between organic matter and tree site quality have been demonstrated by researchers in various areas (Graney and Ferguson, 1970; Della-Bianca and Olson, 1961; Pawluk and Arneman, 1961; Mader and Owen, 1961; Walker and Reed, 1960). Explanations for these relationships have varied with the soils or site conditions studied. In the Boston Mountain Province of northern Arkansas, this relationship was believed to represent varying degrees of hardwood competition during early stages of pine growth (Graney and Ferguson, 1970). Sites occupied by pure pine stands had lower loss-on-ignition values and higher recorded site indexes than sites of similar character occupied by mixed pine-hardwood stands. There was no evidence to suggest that the pure pine stands were on inherently better sites; soils and topography were about the same on pure pine and mixed pine-hardwood plots.

In the present study, similar relationships were found between loss-on-ignition percent of the A1 horizon and site index. Stands of old-field origin, which were usually pure pine, outgrew stands of woods origin (Table 2). Since soils and topography on the field and woods plots were again essentially similar, we conclude that the relationship between loss-on-ignition and site index is mainly a reflection of the amount of hardwood competition early in the life of the stand, as demonstrated by the organic matter incorporated in the Al horizon. Pure pine stands seldom have much incorporated organic matter, even on fairly good sites, whereas large amounts of organic matter are incorporated under hardwoods even on relatively poor sites. Thus, organic matter content of the Al is a measure of hardwood occupancy, and not necessarily a measure of pine site quality.

Depth to Fragipan

The effect of depth to fragipan on shortleaf pine site quality is shown in Fig. 4 (derived from equation [3]). In

Table 2—Mean site index and mean loss-on-ignition percents by woods and old field stands for the various soil groups

Soil group	Site index				Loss-on-ignition	
	Woods		Field		Woods	Field
	meters	feet	meters	feet	%	%
Arkansas Limestone	16.9	55.5 (48 plots)	19.0	62.2 (27 plots)	8.7	6.0
Missouri Limestone and Dolomite	17.0	55.7 (35 plots)	18.9	62.0 (22 plots)	8.0	5.3
Combined Arkansas and Missouri*	16.9	55.6 (83 plots)	18.9	62.1 (49 plots)	8.4	5.7
Arkansas Sandstone	16.6	54.3 (31 plots)	19.3	63.3 (34 plots)	5.3	2.3
Missouri Sandstone	16.9	55.5 (34 plots)	18.7	61.3 (12 plots)	6.3	2.9
Combined Arkansas and Missouri*	16.8	55.0 (65 plots)	19.1	62.8 (46 plots)	5.8	2.5
All Limestone and Sandstone	16.9	55.3 (148 plots)	19.0	62.5 (95 plots)	-	-
Arkansas and Missouri Fragipan soils†	17.2	56.6 (33 plots)	18.7*	61.5 (20 plots)	6.9	5.0

* Values pertaining to the equations presented. † L.I. was not a significant contributor in this equation, but the trend towards higher S.I. on field sites is consistent.

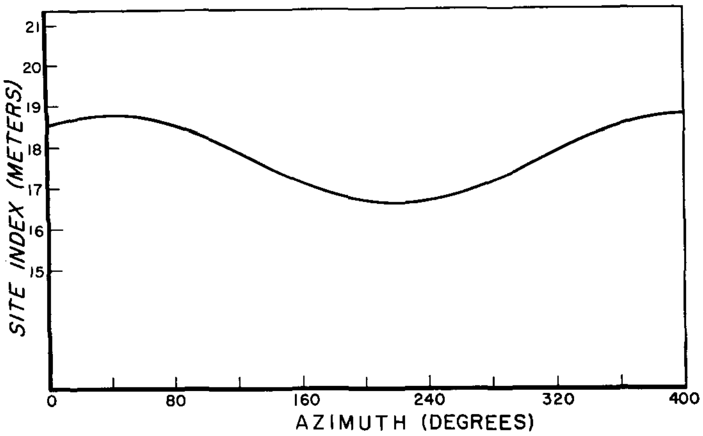

Fig. 5—Relative effect of aspect on site index (Equation [1]).

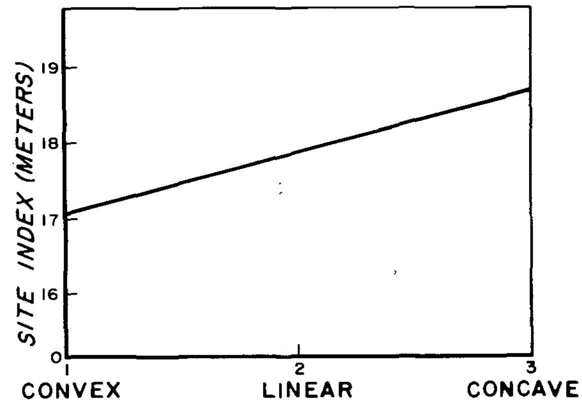

Fig. 6—Changes in site index with slope shape (Equation [1]).

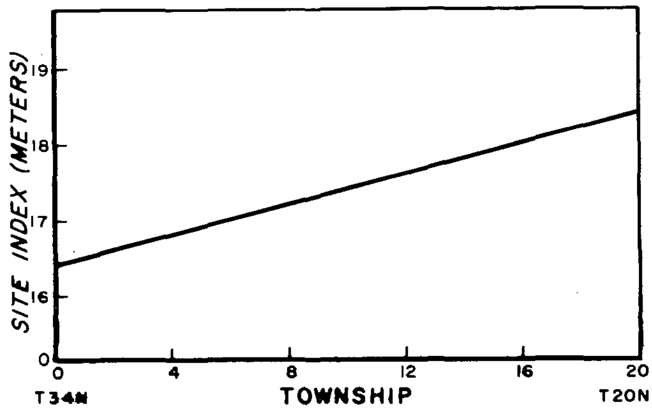

Fig. 7—Changes in site index with changes in latitude as reflected by township number (Equation [1]).

most cases, roots were observed in and below the fragipan layers but seemed to contribute little other than to help sustain life during periods of severe drought. The shallowness of fragipans on all plots in soil group III, 36 to 71 cm (14 to 28 inches), obviously could restrict the soil moisture reservoir sufficiently to reduce pine growth during dry periods. However, a positive contribution of fragipan layers to tree growth could be the reduction of water movement down through the profile during wet periods. Figure 4 indicates that the productive potential for fragipan soils is much the same as that for the soils of the other groups. This similarity could be caused, in part, by the retention of soil moisture by the fragipan, with the major limiting factor being the thickness of the water-holding reservoir above the fragipan.

Aspect, Slope Shape, and Latitude

Topographic features are closely associated with differences in microclimate and soil moisture, which affect tree growth.

Aspect was a significant factor in all of the derived equations. Figure 5 illustrates that northeast exposures were found to produce the best sites while the poorer sites occur on the southwest-facing slopes. This relationship is similar to that reported for the mountains of northern Georgia and northern Arkansas (Ike and Huppuch, 1968; Graney and Ferguson, 1971). Hartung and Lloyd (1969), reporting on site relationships for oak and pine in Dent County, Missouri, observed that the pine was less sensitive to changes in aspect than the oak species, but the best pine sites were also associated with northeast exposures. In the Ozark Highlands, north and east slopes probably have more favorable moisture conditions during the dry summer months than do the south and west exposures. Less direct sunlight on north- and east-facing slopes should produce lower temperatures and lower rates of evapotranspiration, and consequently there should be more moisture available during the growing season than on the south and west exposures.

For the sandstone and limestone soil groups, site quality increased as slopes changed from convex through linear to concave (Fig. 6). Carmean (1967) working with black oak in Ohio and Graney and Ferguson (1971) working with shortleaf pine in northwest Arkansas have also reported significant correlations between slope shape and height growth or site index. The contribution of slope shape to pine site quality is probably due to the interrelationship of several factors. The shape of a slope can affect the rate of surface and subsurface water movement from the site. Convex and linear slopes tend to lose water more rapidly than concave slopes. Severe summer droughts are common in the Ozark Highlands, and small improvements in moisture-retaining capacity of a given site would be advantageous during such periods. Concave, or receiving, positions might also benefit from the thicker A horizons and somewhat greater total soil depths commonly associated with this type of slope.

Site index on limestone soils increased slightly with decreasing latitude (from north to south) (Fig. 7). Latitude was a significant factor on all but pan soils and Arkansas sandstone soils. A similar relationship has also been reported for pine in the loess area of Louisiana and Arkansas (Bassett, 1968). Although geologic formations and parent materials change radically from north to south in the region under study, these changes probably do not account for the changes in site quality within soil groups. Climatic changes with latitude are a more probable explanation. As one moves from the northern to the southern edge of the Province, the average length of growing season increases from 170–180 to 200–210 days, and average annual rainfall increases from 100 to 130 cm (USDA Yearbook of Agriculture, 1941).

CONCLUSIONS

The soil and topographic factors represented in the equations probably reflect soil moisture or climatic properties influencing the site and vegetative competition when the stands were established. Aspect influences evapotranspiration, slope shape affects the degree of surface and subsurface water movement, and depth to fragipan controls potential moisture storage. Latitude, through temperature and rainfall gradients from north to south, reflects length of growing season and potential moisture supply.

Loss-on-ignition values were considered to approximate organic matter levels. The negative relationship of loss-on-ignition to site index on plots representing similar physiographic conditions seems to reflect mainly stand composition. Plots with pure pine stands and low loss-on-ignition values consistently supported taller trees than mixed pine-hardwood stands with higher loss-on-ignition values. One explanation may be that pines in the mixed stands were probably subjected to more severe competition from hardwood stems and sprouts during their earlier years than were the pines in pure stands that originated on old fields.

The equations developed will predict, with reasonable accuracy, expected height at age 50 for existing stands and will be used to derive site estimation tables for field use. Some adjustment will be required, however, if equations [1] and [2] are to be used to predict site index for open land or sites which are to be cleared and planted or seeded to pine. It is suggested under these circumstances that the average loss-on-ignition value found for pure pine stands, 5.2% for equation [1] and 3.0% for equation [2], be substituted in the equations. Presumably, if a stand is artificially regenerated with pine or naturally regenerated under planned management, hardwoods will represent only a minor component of the new stand and organic matter eventually will approximate the level found in natural pure pine stands. This assumption will be tested in studies of changes in organic matter during the life of stands in the Ozark Highlands.

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