SITE INDEX OF YELLOW-POPLAR IN RELATION TO SOIL AND TOPOGRAPHY IN EASTERN KENTUCKY

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Abstract.--An effective forest management program depends to a great extent on the ability to evaluate and delineate forest areas into site quality classes. In areas where trees are not present or trees are not suitable for direct measurement of growth potential, predictive models based on soil and topographic factors may be used to estimate site productivity. This type of model was developed using regression analyses to estimate the height growth of yellow-poplar (*Liriodendron tulipifera* L.) in the Appalachian mountains of eastern Kentucky. Predictive models were also developed for soil type and topographic position. Measurements of selected soil and topographic factors in 48 stands were made. Tree growth was evaluated on 268 dominant and/or codominant yellow-poplars in these stands. Observed variation in site index for all sample sites was 14.6 m, however, within individual soil types the largest variation was 9.8 m. Prediction equations were of the form: Log (tree height) $= b_0 + b_1X_1 + b_2X_2 + \ldots + b_nX_n$, where X_1 is the reciprocal of tree age. Significant correlations ($p = 0.01$ level) were found between tree height (with age accounted for), and the following soil variables: thickness (cm), organic matter content (%), pH of the A horizon and the thickness of the A plus B horizons (cm). Stand basal area (m^2/ha) was also correlated with tree height. Approximately 45 percent of the variation in tree height was accounted for by the regression. Prediction equations for individual soil types and topographic positions explained up to 83 percent of the variation in tree height.

Keywords: *Liriodendron tulipifera* L., site index, prediction equations, site classification, forest soil properties.

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INTRODUCTION

Sound forest management requires knowledge of site potential and an ability to evaluate and delineate forest areas into site quality classes. One direct measure of site quality is site index which is the average height of dominant and/or codominant trees of a single species at a reference age (usually age 50 for the eastern United States). Once site quality is assessed through measuring site index, silvicultural practices can be concentrated on sites capable of enough growth to justify these practices. However, when land being evaluated does not support trees of appropriate age or the desired species to allow direct measurement of site index, an indirect method which correlates tree growth to certain soil and topographic features may be used for estimates.

Yellow poplar (*Liriodendron tulipifera* L.) is one of the more valuable hardwoods of this region and is an important component of the mixed mesophytic forest (Fowells 1965, Martin 1975). It is also one of the most exacting in site requirements (Auten 1945). In recent years several studies have related yellow-poplar growth to soil and topographic factors. Tryon *et al*. (1960) found the thickness of the A1 horizon to correlate best with height growth in Indiana. In the Virginia-Carolina Piedmont region Della-Bianca and Olsen (1961) determined surface soil thickness, organic matter content, and sand content to be related to height growth. Phillips (1966) correlated surface soil drainage to height growth in New Jersey. Ike and Huppuch (1968) predicted height growth from the organic matter content, thickness, and drainage of the A2 horizon and clay content of the B2 horizon in the Georgia Blue Ridge Mountains. They also observed that yellow-poplar seldom occurred on southeast, south, and southwest facing slopes. In southwest Virginia, Van Lear and Hosner (1967) reported poor correlation between height growth of yellow-poplar and soil mapping units because of the wide variation of site indices within each of the soil mapping units studied.

The present study determined correlations between soil and topographic factors and height growth of yellow-poplar in four eastern Kentucky counties. The objective was to derive prediction equations for yellow-poplar height growth from easily measured soil and topographic variables.

METHODS

Field and Laboratory Measurements

A total of forty-eight essentially pure, even-aged yellow-poplar stands, distributed over a wide range of soil and topographic conditions, were sampled in Breathitt, Knott, Leslie, and Perry counties located in the Appalachian mountains of eastern Kentucky. The stands ranged in age from 30 to 70 years, were well-stocked, and showed no evidence of fire, grazing, or recent cutting. Slope, aspect, soil type, and slope position were relatively uniform for the sampling area within a stand. Site index (S.I.) was determined for each stand from conventional site index curves (Beck 1962) using height and age measurements from an average of six dominant and/or codominant yellow-poplar trees. Age was determined for each tree using an increment borer to obtain cores for ring counts and height was measured with a Haga altimeter. Slope position was determined as distance from the plot to the

ridge divided by slope length. Percent slope was measured with an Abney level and slope aspect was measured with a hand compass. Topographic configuration was judged to be cove, side slope, or stream terrace. Slope shape was specified as being convex, concave, or plane. Basal area was measured with a 10-factor prism.

Four soil series were represented on sample sites: Cutshin (Typic Haplumbrepts; Fine-loamy, mixed, mesic), Shelocta and Gilpin (both Typic Hapludults; Fine-loamy, mixed, mesic), and Pope (Fluventic Dystrochrepts; Coarse-loamy, mixed, mesic). Cutshin soils are deep, medium-textured, well-drained, with a thick, dark surface. Shelocta soils are similar except their surface horizon is lighter in color and thinner. Gilpin soils are not as deep and have a higher clay content in the subsoil than Shelocta. The Cutshin and Shelocta soils were developed in colluvium of variable thickness and occur on side slopes. The Gilpin soil developed in residuum. The parent rock consists of alternate layers of acid sandstones, siltstones, and shales of the Pennsylvanian era. Pope is a coarse-textured, moderately deep to deep, well-drained, light colored alluvial soil that occurs on stream terraces. The water table fluctuates with the level of the adjacent stream.

At each sample site a soil pit was dug, the soil profile was described, soil series identified, and bulk soil samples collected from each genetic horizon. Soil samples were air dried and ground to pass a 20-mesh screen. The pH of each horizon was determined using a 1:1 soil to water paste. Total nitrogen (N) and organic matter content was determined for all A horizons using a macro-Kjeldahl method and the Walkley-Black procedure, respectively (Allison 1965). Total N content in the surface 30 cm was computed by using mean bulk density for each soil series.

Analysis of Data

Stepwise multiple regression analysis (Barr et al. 1976) was used to determine regression coefficients of significant variables ($p = 0.05$) so as to develop prediction equations for yellow-poplar height growth utilizing data from all 48 sample sites. LOG_{10} of tree height was chosen as the dependent variable and the reciprocal of age as the independent variable because their use produced the larger multiple correlation coefficient (r^2) values than other forms of tree height and age.

The sample sites were categorized by 1) soil series (Cutshin, Shelocta, Gilpin, and Pope), 2) topographic configuration (cove, side slope, and stream terrace), and 3) slope position (upper, middle, lower, and stream terrace). Prediction equations for height growth were developed for each classification within these categories using the stepwise procedure.

A height on age curve was generated for each classification within each category by substituting the means of the independent variables into each prediction equation and varying the age variable from 30 to 70 years at two-year intervals. This range in age was in accordance with the range in ages observed in the field. The Kolmogorov-Smirnov (K-S) two-sample, one-tailed test (Siegel 1956) was used to compare height on age curves between each soil series, slope position, and topographic configuration. This test determined

significant differences in site indices between subgroups within the same category.

RESULTS AND DISCUSSION

Relationships between height growth of yellow-poplar and several topographic and soil physical and chemical factors were statistically significant. Regression equations relating various topographic and soil variables to tree height were of the form: Log (tree height) = $b_0 + b_1X_1 + b_2X_2 + \ldots + b_nX_n$, where X_1 is the reciprocal of tree age.

Table 1 summarizes variable means for the categories of soil series, topographic configuration and slope position. Table 2 presents the height prediction equations for the same categories with their respective r^2 values.

Ninety-two percent of the sample plots were located on north to east aspects. This reflects the influence of aspect on microclimate which influences the natural distribution of yellow-poplar in this area of eastern Kentucky. This follows the same distribution of yellow-poplar found by Ike and Huppuch (1968) in the Georgia Blue Ridge Mountains, i.e. yellow-poplar seldom occurred in measurable stands on southeast, south, and southwest slopes. Hutchins et al. (1975) noted significant differences in vegetation types on opposing slopes in eastern Kentucky due to microclimate and soil.

The variables in the general height prediction equation (Table 2, Part I) for yellow-poplar included both physical and chemical soil factors. Soil characteristics related to increased rooting volume and available soil moisture, such as thickness of the A and B horizons and organic matter content of the surface soil, were correlated with increased height growth. The pH of the A horizon was also directly correlated with height. Site quality improved with an increase in pH and organic matter content of the A horizon. On these sites, the A horizons may be showing the effects of enhanced tree growth and nutrient recycling rather than being the cause of the greater growth observed due to the soil enriching ability of yellow-poplar. Also, the organic matter content is an important source of cation exchange capacity in these soils. The A horizon pH of most soils was in the range normally recommended for yellow-poplar (5.5 to 6.5) with a few as low as 4.9.

Usage of these prediction equations should be limited to sites comparable to the study plots and values for the factors used in estimating tree heights should be within the range of factors in the study. The four soil series that were sampled in this study have been mapped extensively in the Appalachian Mountains of Kentucky and can be expected to show considerable variation in many soil properties related to variability in parent material, slope, and past land use.

Comparison of Site Productivity Between Soil Series

Height prediction for yellow-poplar growing on a particular soil type was generally more reliable from data collected within the type than the general equation derived from all sample sites (Table 2, Part II).

Table 1.--Abbreviation key and mean values of ten independent soil, topographic, and stand variables by soil series, site exposure, and slope position.

Variables (abbreviation)	Soil Series				Topographic Configuration		Slope Position		
	Cutshin	Shelocta	Gilpin	Pope[1/]	Cove	Side Slope	Upper 1/3	Middle 1/3	Lower 1/3
Slope (%) (Slope)	44	47	55	3	46	47	48	45	49
Thickness of A horizon (cm) (Thik A)	28	18	15	19	24	21	25	20	24
Thickness of B horizon (cm) (Thik B)	93	97	69	88	98	89	83	96	91
Total depth (cm) (Depth)	121	115	84	107	122	109	108	116	114
pH of A horizon (pH-A)	6.0	5.8	6.1	5.6	6.0	5.8	6.1	6.0	5.8
pH of B horizon (pH-B)	5.5	5.4	5.6	5.6	5.6	5.4	5.5	5.4	5.4
Organic matter content of A horizon (%) (O.M.A.)	5.1	4.9	4.8	3.7	4.5	5.3	4.7	5.0	5.0
Nitrogen concentration of A horizon (%) (N-A)	0.52	0.30	0.31	0.23	0.45	0.36	0.54	0.38	0.35
Nitrogen content of surface 30 cm (kg/ha) (N-30)	8,700	5,940	6,710	4,230	6,940	7,270	7,820	7,120	6,830
Basal area (m^2/ha) (B.A.)	22.9	22.7	20.5	19.2	23.7	21.6	24.7	22.3	21.6

[1/] Sites classified as Pope soils were also classified as stream terrace sites due to their topographic location. These sites were considered to be a fourth category in slope position comparisons, and a third category in topographic configuration comparisons.

Table 2.--Multiple regressions relating total height of yellow-poplar to soil and topographic variables with variability accounted for.

	Regression Equations	r^2
I. General (n=48)[1/] (268)[2/]	Log Height = 1.3449-5.5321 (1/Age)+0.0002 (O.M.A. X Thik A)+0.0019 (B.A.)+0.003 (Thik A+B)+0.0266 (pHA)	0.45
II. Soil Series		
Cutshin (n=17) (94)	Log Height = 1.3998-4.5270 (1/Age)+0.0044 (B.A.)+0.0404 (pHA)+ 0.0006 (Thik B)-0.0374 (pHB)	0.74
Shelocta (n=20) (115)	Log Height = 1.4059-4.3384 (1/Age)-0.0004 (Depth)-0.0126 (O.M.A.)+ 0.0447 (pHB)+0.000005 (N-30)	0.50
Gilpin (n=4) (21)	Log Height = 0.9560-1.9580 (1/Age)-0.0010 (Slope)+0.0070 (Depth)	0.74
Pope (Stream Terrace) (n=7) (38)	Log Height = 1.7590-3.4132 (1/Age)-0.0072 (B.A.)-0.0202 (O.M.A.)	0.26
III. Topographic Configuration		
Cove (n=17) (94)	Log Height = 1.5023-8.4980 (1/Age)-0.0024 (B.A.)+0.0007 (Depth)+ 0.0200 (pHA)+0.0070 (N-A)	0.46
Side Slope (n=24) (136)	Log Height = 1.1900-3.7189 (1/Age)+0.0064 (B.A.)+0.0010 (Thik A)+ 0.0282 (pHA)+0.0004 (Thik B)	0.62
IV. Slope Position		
Upper 1/3 (n=6) (34)	Log Height = 1.7458-8.7143 (1/Age)-0.0064 (Slope)+0.0006 (Depth)+ 0.0319 (pHA)	0.83
Middle 1/3 (n=23) (126)	Log Height = 1.4024-4.4212 (1/Age)+0.0006 (Slope)+0.0002 (O.M.A. X Thik A)+0.0019 (B.A.)+0.0008 (Depth)	0.50
Lower 1/3 (n=12) (70)	Log Height = 1.1978-2.9822 (1/Age)+0.0004 (O.M.A. X Thik A)+0.0054 (B.A.)+0.0061 (O.M.A.)+0.0254 (pHB)	0.76

[1/] Number of sample sites.

[2/] Number of sample trees.

Equations for the Cutshin and Gilpin series explained 74 percent of the variation in tree height followed by Shelocta series at 50 percent. The variation explained by the equation for the Pope series (stream sites) dropped below that of the general equation (26 vs. 45 percent).

Site index at base age 50 (Fig. 1) was highest on the Cutshin soil (31.2 m) followed in decreasing order by the Shelocta (30.2 m), Pope (29.3 m), and Gilpin (27.7 m). Cutshin soils were probably more favorable for yellow-poplar growth because they have thicker A horizons with higher organic matter contents and less acidic pH than the other three soils. Gilpin soils were the least favorable for yellow-poplar growth probably because of shallow depth, finer textured subsoil, and limited water storage capacities. Smalley (1964) and Trimble and Weitzman (1956) previously found that soil depth influenced height growth of yellow-poplar in Alabama and oaks in West Virginia and Maryland, respectively.

Shelocta and Pope soils were intermediate in site quality. However, site quality of Pope was significantly lower than Shelocta which may be due to the sandy texture of the Pope, i.e. the Pope is less fertile than the Shelocta because of a lower organic matter content and lower cation exchange capacity.

Comparison of Site Productivity Between Topographic Configurations

The three slope configurations compared were coves, side slopes, and stream terrace sites. Coves generally were concave in shape, while side slopes were plane to convex. The equation for side slope positions explained 62 percent of the variation in tree height as opposed to only 46 percent for the cove sites (Table 2, Part III). The stream terrace site equation is the same as the equation for the Pope series within which only 26 percent of the variation in tree height could be explained.

Site index curves generated for each configuration revealed that on cove sites early growth was slow but above age 35 growth was greater than on side slopes and stream terraces (Fig. 2). Site index for side slope and stream terrace positions were not significantly different. Site index values (base age 50) for each configuration followed the same trend; 32.6 m for coves, 30.3 m for side slopes, and 29.7 m for stream terraces. Similar results have been reported by Auten (1945) in Kentucky and adjacent states, and by Ike and Huppuch (1968) in the Georgia Blue Ridge Mountains.

A possible explanation for coves being more favorable for yellow-poplar growth is that these areas are more protected from winds, thus evaporation is decreased and available moisture is increased. This slope shape would also tend to concentrate subsurface soil moisture. Since stream terraces are also protected, the higher site quality of coves versus the lower site quality of stream terraces may be attributable to the lower fertility of the coarse-textured stream terrace soils and the fluctuating water table may restrict rooting depth. These coarse-textured soils potentially are subject to more nutrient leaching than the protected coves, reducing the efficiency of nutrient recycling.

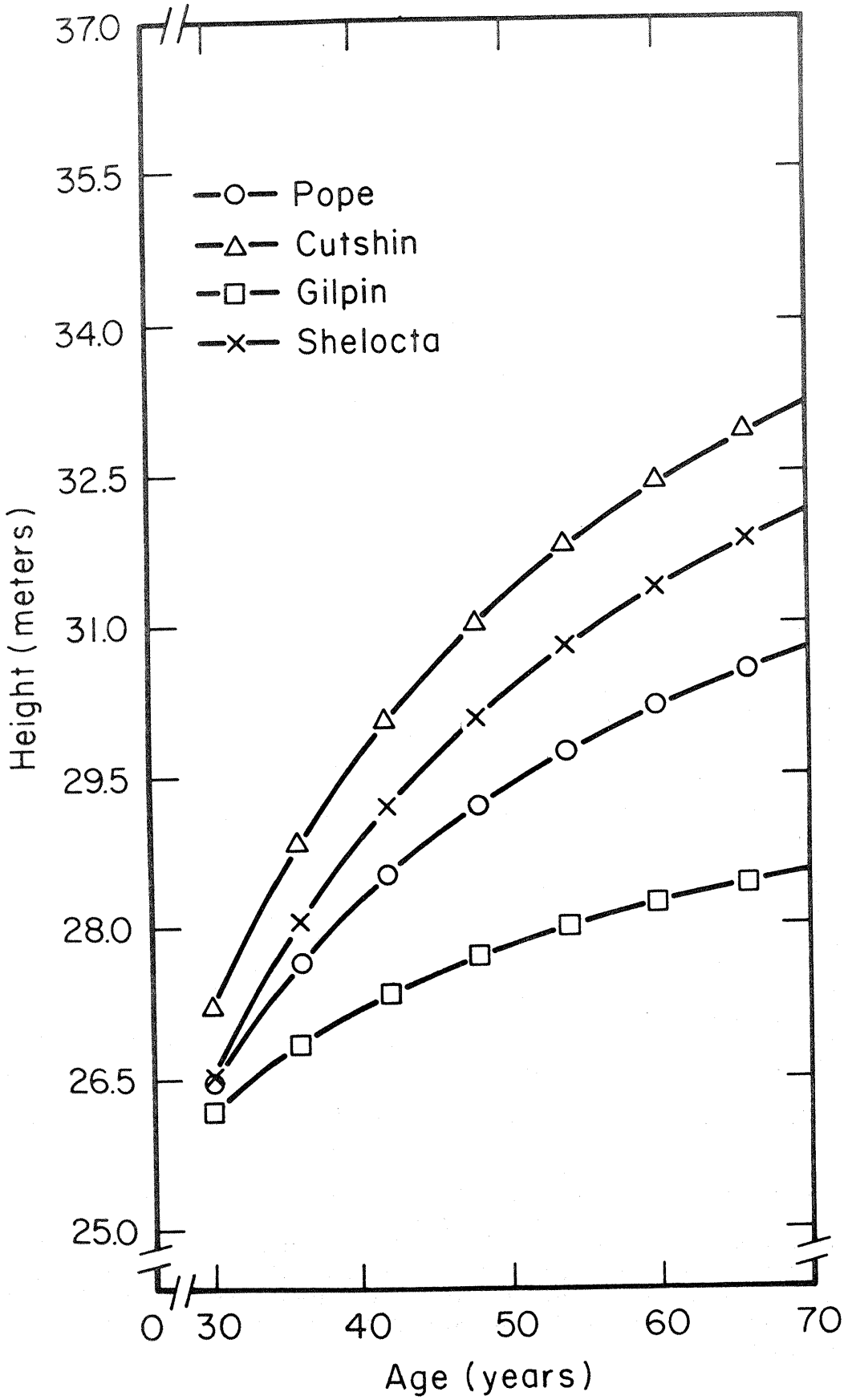

Figure 1: Site index curves of yellow-poplar growing on four soil series.

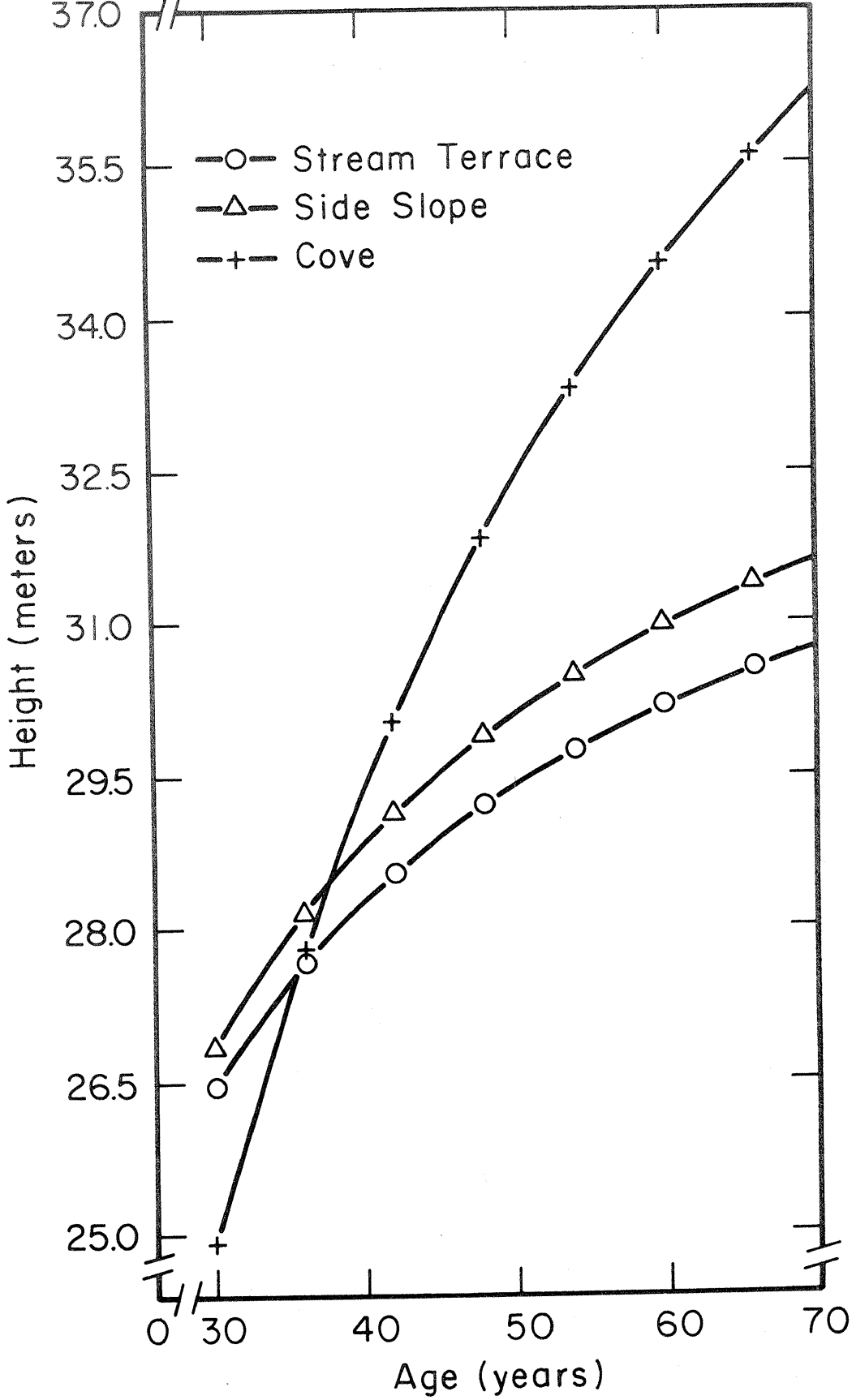

Figure 2: Site index curves of yellow-poplar growing on three topographic configurations.

Comparison of Site Productivity Between Slope Positions

Variation in tree height explained by each regression was 83 percent for the upper slope, 76 percent for the lower slope, and 50 percent for the mid slope (Table 2, Part IV). These were all better predictors of tree height than the general equation. The equation presented earlier for the Pope series corresponds to the stream terrace subgroup and had the lowest r^2 value (0.26).

Site index values (base age 50) ranked highest for the upper slope (33.5 m) followed in decreasing order by the middle slope (30.9 m), stream terrace (29.8 m) and the lower slope (29.4 m) (Fig. 3). Contrary to Smalley's (1964) findings in Alabama and Tennessee, for trees beyond age 35, tree height increased with increasing distance up the slope. This trend may be due to the higher percentage of sample sites which were classified as Cutshin soils and cove sites in the upper slope position. Fifty percent of the upper slope sites were Cutshin soils, while 67% were cove sites. The Cutshin soil and cove site are more favorable for yellow-poplar. Conversely, the lower slope position had 58% of the sites as Shelocta soils and 75% as side slope sites. The Shelocta soil and side slope sites are both less favorable for yellow-poplar than either the Cutshin soil or cove site.

This trend also deviates from trends observed in other soil-site studies of black oak in Ohio (Carmean 1965) and yellow-poplar in the Georgia Blue Ridge Mountains (Ike and Huppuch 1968), where lower slopes were more favorable for tree growth. However, in western North Carolina, Beck (1977) observed one stand of yellow-poplar trees of sprout origin growing on an east-facing slope (S.I. = 33.6) that had a higher site index value than did a similar stand growing in a stream bottom (S.I. = 24.4). He attributed this difference in productivity to poor soil drainage in the stream bottom. In this study the bottoms were well-drained however, the fluctuating water table and sandy texture of the soil may contribute to the lower site productivity.

CONCLUSIONS

Regression analysis of topographic and soil variables generated a prediction equation for yellow-poplar height growth. Prediction was improved when data were stratified by soil type, slope position and topographic configuration. The significant variables in predicting tree height (with age accounted for) were, in decreasing order of importance: the product of the thickness of the A horizon and percent organic matter content of the A horizon, basal area, pH of the A horizon, and thickness of the A plus B horizons. These variables explained 45 percent of the variation in tree height.

Cutshin soils were most favorable for yellow-poplar growth probably due to a thicker surface horizon which contained more organic matter and was less acid than the other soils. Gilpin soils were least favorable for yellow-poplar growth because the shallow depth reduced water storage capacity and rooting volume.

Differences in site quality due to topographic configuration indicated that coves were more productive than side slopes and stream terraces.

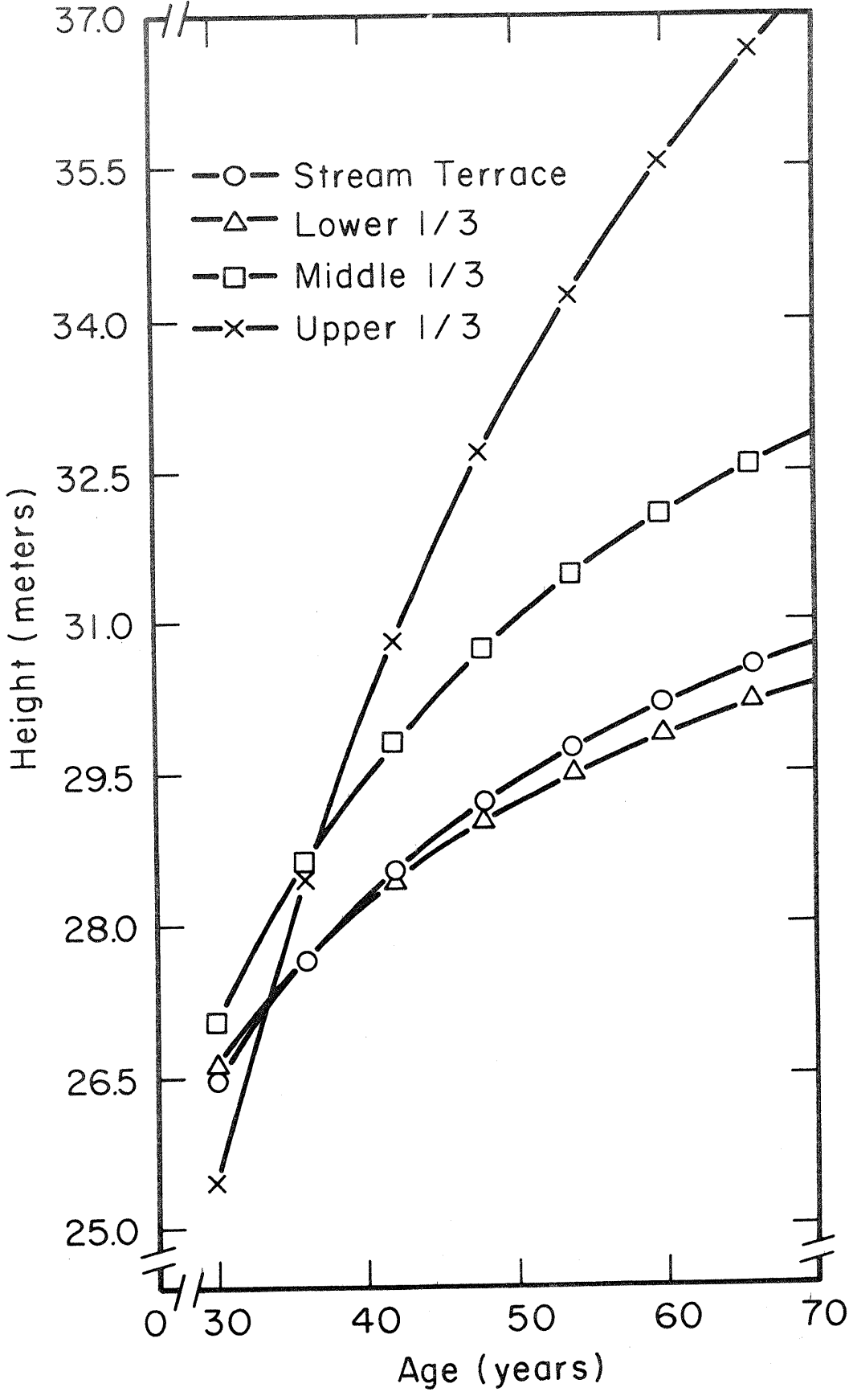

Figure 3: Site index curves of yellow-poplar growing on three slope positions and stream terraces.

Site quality increased with distance up the slope from the stream. The upper and middle slopes had the highest site indices, while lower slopes and stream terraces had lower site indices.

Prediction equations for soil series, topographic configuration, and slope position accounted for a larger portion of the variation in tree height than did the general equation. When the sampling range was confined to a specific area or site condition, the prediction equation had higher r^2 values and should be more reliable. Aggregation of data introduced more variability into the height prediction equation. We conclude that selected soil properties, slope position, and topographic configuration are factors that determine a sites suitability for growth of yellow-poplar. The height prediction equations should be applicable throughout the eastern Kentucky mountains.

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