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The Relation of Soil and other Site Factors to Forest Composition and Productivity in West Tennessee

Edwin Atkins Hebb
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To the Graduate Council:

I am submitting herewith a dissertation written by Edwin Atkins Hebb entitled "The Relation of Soil and other Site Factors to Forest Composition and Productivity in West Tennessee." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Botany.

Royal E. Shanks, Major Professor

We have read this dissertation and recommend its acceptance:

Harry Klepsen, Fred H. Norris, M. E. Springer, Gordon Eubert, Lloyd Seatz

Accepted for the Council:

Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

7 December 1960

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Dean of the Graduate School

THE RELATION OF SOIL AND OTHER SITE FACTORS TO FOREST COMPOSITION AND PRODUCTIVITY IN WEST TENNESSEE

A Dissertation

Presented to

the Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree

Doctor of Philosophy

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by

Edwin Atkins Hebb

December, 1960

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CHAPTER I

THE PROBLEM AND DEFINITIONS OF TERMS

Forests are important in the economy of Tennessee because so much of the state is forested. Half of west Tennessee, for example, is in forest, and since no other productive use is likely for the marginal land so used, it will probably remain forested.

According to a report prepared by the Tennessee Forest Industries Committee in 1957, industries based ultimately on the forests number about one-third of all manufacturing establishments in the state. In west Tennessee, with half of the area actually in forest, the forest economy forms a large part of the total economy of a region of limited agricultural potential.

The forests of west Tennessee are made up of many species of hardwoods. Oaks and gums and tulip poplar occur on most sites of the region, but the principal commercial species are southern red and white oak in upland forests, and in the bottoms, sweet gum and cherrybark oak. On the more moist upland sites tulip poplar is common.

This is the so-called "Brown Loam" area (Figure 1), named for the characteristic soils. This term is now considered inappropriate, since the soils are mostly silt loams rather than loams. They are derived from loess, often with an admixture of sands from the underlying Coastal Plain sediments.

As resources, the forests of this area should be fully developed, and for full development, the forest sites must be well understood. Some

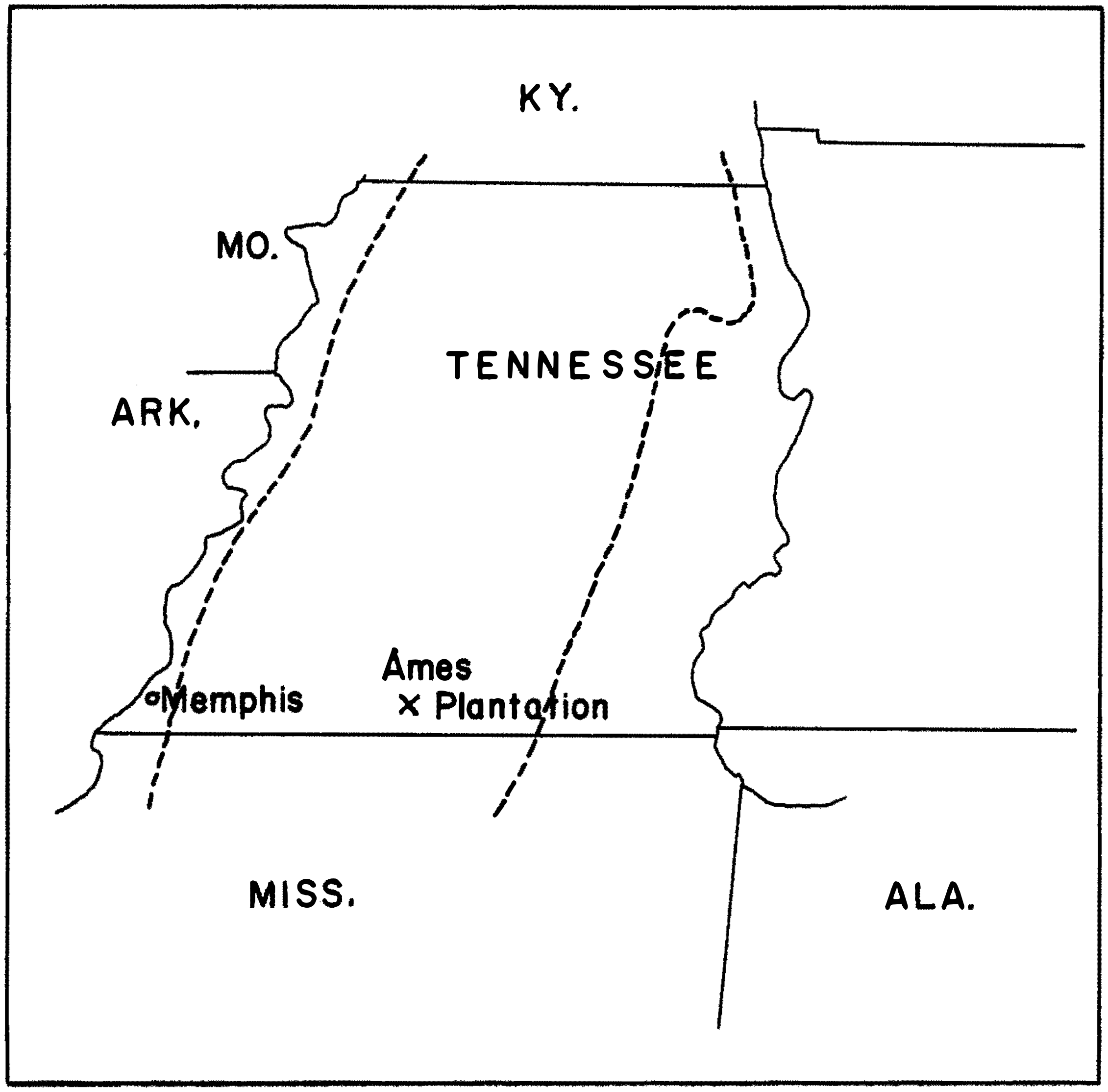

Fig. 1. The region of loess-derived soils in west Tennessee, showing the location of the study area (X). The boundaries shown (dashed lines) are adapted from those of the Memphis-Grenada soil association as presented in Soils and Men (United States Department of Agriculture 1938).

of them are capable of producing special products of great value. White oak, for staves and veneer, for example, yields a fine product on some soils of west Tennessee. On other soils it is far inferior.

The present study is an attempt to measure the variation of forest productivity in this region and its relation to differences in the characteristics of the soils of the region. Knowledge of forest productivity of soils is invaluable to the forest owner or speculator, for it is the basis of sales and purchases of land.

The forest manager, too, finds the knowledge of land productivity essential. He is interested in how much can be invested in cultural measures, and also in a purely silvicultural sense in how species grow on certain soils--in determining where established reproduction can be relied upon, for example. In many areas tulip poplar seedlings may be present, but only on suitable sites will they survive until they are fully developed.

With the construction of new pulp mills in and near the area there is pressure to convert forests to pine, and indeed this is advisable on some sites. But it is not advisable on all sites, and the problem is to obtain knowledge defining the potentialities of the sites and the suitability of the species. The manager must know what kind of forests he should be working toward, and he should know what yields to expect.

A. THE PROBLEM

The objective of the study was to lessen uncertainties in the management of forest land of a specific area in west Tennessee by

determining the relationship between species composition and productivity of forest lands and soil and site factors. Specific objectives were to determine species suitabilities of forest sites of the Ames Plantation and the productivity potentials of these sites.

The ultimate objective was the description of sites of varying potential in the "Brown Loam" area so that the characteristics of representative sites would be known and the potential and type of growth on any site could be predicted.

Once the potentiality of the site was determined using the height at fifty years as a standard, then the task would be to develop a forest land rating system suitable for treeless as well as forested areas. If productivity of the sites could be related to some easily measurable permanent characteristic of the site, then this could be used as a site indicator.

Species composition might be related to site potential closely enough to allow it to be used for prediction. If so, then the relationship between study trees and forest composition could be used in reverse order to predict the growth on a site as revealed by its present composition.

In short, the study was an examination of sites in the region to discover the interrelations between site potential, soil characteristics, and species composition.

Scope

The study was restricted to hardwood forests on an 18,000-acre farm in the so-called "Brown Loam" region of west Tennessee. The species

studied were five trees of the region which were important to the economy of the area and which covered the range of sites on the Ames Plantation.

B. DEFINITIONS OF TERMS

Exposure. This refers to the direction in which a slope faces. An alternate term, "aspect", will not be used, since it is likely to be confused with the term for the seasonal stage of vegetation ("the autumnal aspect"). Exposure is also used by some authors for the relative openness of the site: "Exposure may be stated in terms of the position of an area with respect to adjacent land as for example ridge *vs*. cove or draw." (Coile, 1952, p. 396). It will not be so used in this report.

Height at fifty years. This is analogous to site index (see below), but is derived from single trees. It is not an average.

Site. "Site" is the total environment of any tree.

Site index. This is a site productivity rating customarily defined as the height of the dominant trees at fifty years. This figure is an average.

Tree site index. This term is used in this report to refer to site index determined from the empirical height growth curve of a single tree.

Uneven-aged stands. These are timber stands in which the trees are not of the same approximate age, as they would be in a plantation where the trees were all planted in the same year. The uneven-aged stand

contains many ages of trees from seedlings to mature or over-mature trees. Often the term "all-aged" is used for stands of this type, but since this term implies that all ages are present, and this is almost never the case, it will not be used.

CHAPTER II

HISTORY AND LITERATURE

A. CLASSIFYING FOREST LAND

The best way to determine the productivity of forest land is from actual yield of forests upon that land. In most cases, however, productivity records are not available, and for immediate data to guide management the yields must be estimated.

Site may be estimated and the land placed in one of a number of classes according to its apparent productivity. This is the system commonly used in Europe. Thus a site may be classed as I, II, III, IV, or V depending on its productivity rating (the sites are customarily divided into five classes). A class I site is the best.

Site may be estimated indirectly from some factor present in the site that is believed to be critical. The degree of its presence, or its presence alone, may be used as a criterion of site class. The so-called plant indicators are used this way, and the same assumption is used when site quality is associated with various soil and environmental factors. Land with no vegetation on it is linked through one of these factors to land on which the yield is known or can be measured. Thus on non-forested sites the factors may be studied and yields predicted according to their combination and magnitude.

Plant indicators are understory plants on the site that are supposedly characteristic of certain site qualities. They are popular because small plants may be present whether or not forests are, and

because they are affected by site conditions and develop quickly. Succession in such communities proceeds rapidly (Shantz, 1911, and Korstian, 1919).

Plant indicators, though they have been successfully used in northern Europe, have not worked well in the United States, apparently due to too much reliance on the indicator value of single species. Kittredge (1938) considered community groups much better indicators. He regarded individual species as poor indicators of soil differences because the infrequent plants were too infrequent and the common ones too common.

There are other drawbacks: species found growing in a stand of trees grow under different conditions, and hence may be quite different from species growing on a treeless site. Boyko (1945) maintained that this is an advantage because lesser vegetation used as indicators may reveal conditions of silvicultural importance which the less sensitive trees would not show.

Long (1953) presented a highly developed statement of the plant indicator approach. Trees were indicative of the climate and soils and geology of the country, and "The shrubs and ground vegetation indicate the finer details of the site." (p. 155)

Yield itself is measured in volume, but indices of production may utilize only one of the dimensions entering into volume calculations. An index utilizing height, for example, is the most common productivity rating system on the American continent. This is the "site index", the average height of the dominant trees of a stand at a standard age. In

the southern United States 50 years is ordinarily used. Where timber grows to maturity in a longer period greater ages may be used as standard (100 years in Douglas fir). Jackson (1960) points out that site index is based on the effects that critical environmental factors have on the first part of the exponential portion of the growth curve. The expression of the growth curve in site index is indicative of the productivity of the site.

Site index is not easy to determine in uneven-aged stands. In such stands it is difficult to get any average tree measurement because the trees are of many sizes, and doubtful whether any such average would fairly represent the potential of the site as conventionally estimated from even-aged stands.

B. HEIGHT GROWTH IN TREES

Height growth is used as an indicator of the productivity of the site because it is less affected by competition than diameter growth and is believed to be closely dependent upon the various conditions of the site. As Büsgen and Münch (1929) say, the "rates of height-growth, dependent on internal causes, are very greatly modified by the influences of the locality, so much so, that in forestry height growth serves as the best measure of the quality of the locality." (p. 16)

Annual Height Growth

Within the tree itself, height growth is not an isolated process, but is correlated with many other characters. Though the plants he studied were seedlings, Wenger (1955) found that height growth correlated

well with quantitative measures of many stem characteristics. The ratio of diameter to length of stem, the length of terminal bud, needle length, number of branches, and total height all were related to height growth.

Most studies show that height growth starts early in the year and ends early. Friesner (1942), in studying height growth in four species in Indiana, found that less than ten percent of height growth occurred after the so-called grand period of growth. Similar observations have been reported by Kozlowski and Ward (1957), Husch (1959), and others.

Growth differs in different species. Some have a short season, and others have a longer season. Kienholz (1941) found that while many species (white ash, red oak, beech, and sugar maple) started and finished growth early, others (white birch, gray birch, tulip poplar, and poplar) grew from mid-June to mid-August. There seem to be different types of height growth curves: a sharp upward curve that flattens off in a week or so for some species, and for others a long slow climb with no abrupt flattening off (Johnston, 1941).

Growth Throughout the Life of the Tree

According to Kozlowski (1955), the shape of the growth curve (and its length) is controlled mostly by hereditary factors. This would also apply to the curve of cumulative growth. The curve produced is sigmoid, beginning with a gradual increase of growth rate, and ending with a gradual decrease. First there is a phase when growth is very slow; then follows the "exponential phase" when growth increases to the maximum; and thereafter follows the decline of growth. "As maturity is reached, the height curve begins to flatten out until in old timber

heights increase by very small additions per year, even by an inch or two" (Chapman and Meyer, 1949, p. 340). Data from oaks harvested on the Ames Plantation in 1958 show such a decline in height growth in the older life of the trees (Table I).

TABLE I. Decline of height growth with age

Tree no.	Species	Age	Mean annual height growth	
			Entire Stem	Top 1 or 2 feet
1	White oak	106 yrs.	0.89 ft.	0.50 ft.
2	White oak	121 yrs.	0.75 ft.	0.16 ft.
3	White oak	93 yrs.	1.02 ft.	0.22 ft.
4	Southern red oak	76 yrs.	1.09 ft.	0.10 ft.
5	Southern red oak	90 yrs.	1.10 ft.	0.26 ft.

Kienholz (1941) and Cook (1941) both noted a constancy in the type curve of any species which was the same from year to year. Kienholz said,

> In the case of white ash, growth started, reached its peak, and ceased at about the same time in each of the four years during which measurements were made. In only one year, 1939, was the peak reached a week later than in the other three years. The growth curves of red oak were likewise similar for the four years, although not as nearly alike as the curves of white ash. This similarity was true also for red maple and red pine. Those species which had a longer growing season, such as larch and the birches, showed a greater amount of variation in the growth curve from year to year because of seasonal differences of temperature and other factors, although the general shape of the curves was similar. (p. 253)

Most of the literature concerns seasonal growth rather than growth over the life of the trees observed. Study of this literature indicates, however, that cumulative height growth (growth throughout the life of the

tree) is controlled by hereditary factors; differs by species; and within species, follows similar patterns.

C. CORRELATING PRODUCTIVITY AND SITE FACTORS

In the years since World War II much effort has been devoted to testing correlations of forest productivity with various factors of the particular sites. The purpose has been to establish some gauge other than growth or yield that would be available on sites where there was no forest growth. The ultimate criterion of productivity was still yield. The correlation of environmental factors with yield, however, while not necessarily implying causal relationships, could be used as an aid in evaluating non-forested sites. This type of work was needed to allow better estimation of growth on sites bearing no trees, or bearing trees of far too young an age to allow accurate forecasting of expected yield.

Commonly these tests were made by using conventional methods of tree height and age measurement on sites where forests were present. When site index was determined and the factors of the environment measured upon a number of such sites of differing potential, variation in the factors could be compared with variation in the site index to see whether they were correlated. If any of the factors or a combination of some of them was correlated with variation in site, then the factors or their combinations could be used in an equation to estimate site. This is a well known approach and has been attempted in even-aged stands with many species of trees, using a formidable array of factors. Some of

the experience with the factors has been as follows:

Topography

Potzger (1939) maintained that next to climate topography was the most important factor in determining forest types in a region. A study by Gaiser (1951) of white oak yielded statistical proof that "positioning of the land" was the most important factor considered. Many investigators have found effective differences in site index associated with differences in topography. Schomaker (1957) found growth of yellow poplar better in the bottomlands. Arend and Gysel (1951) found yields of red and black oaks in southern Michigan were better on lower slopes than on upper slopes. Working with Collins (1948) on eastern red cedar, Arend found that in the Ozarks this species grew better on lower slopes. Hills (1950), working in Canada, went further into the effect, maintaining that ". . . the same slope types do not always occupy the same position on the slope. . . .", but shift according to variation in permeability and available moisture that appear to be functions of slope alone (p. 32).

Effective differences in topography are not restricted to the steeper slopes. Beaufait (1956) studied willow oak on alluvial sites in the Mississippi Valley and found that within the bottomland areas "small variations in relief on Mississippi River alluvium make for large differences in site index." In an entirely different area Smith (1957), using this classification of bottomland sites, found that Beaufait's topographic positions held for mapping site quality of cottonwood lands in the Lower Fraser River Valley in British Columbia.

Coile (1952), studying soil features and the growth of shortleaf and loblolly pines on the Piedmont Plateau of North Carolina, found that site index increased as the sites progressed from ridges to lower topographic features (lower slopes and bottoms) but the effect was not independent of differences in the soils, specifically, of increasing depth of surface soil.

This has been the conclusion of other studies; the productivity differences associated with site differences are often attributed to greater available moisture due to an increase in soil depth. Arend and Collins (1948) noted the effect of greater depth to unconsolidated parent material upon red cedar. Einspahr and McComb (1951), studying site index of oaks in loess-derived soils of Iowa, found differences due to topography and attributed them to moisture differences. Schomaker (1957) found that growth of yellow poplar correlated directly with moisture--growth was best on the bottomland sites.

Tarrant (1950) called attention to several other soil factors related to moisture which probably played an important role. He distinguished convex topography ("ridges, hilltops, and upper slopes) from concave topography ("lower slopes, valleys, and basins") and concluded that

> The predominating effect of convex topography on the site is to impoverish the soil of fine material and humus through erosion and to remove soluble salts and moisture through drainage. . . . The predominating effect of concave topography on the site is to build soil by deposition of fine material, soluble salts, and moisture from higher-lying lands." (p. 724)

Aandahl (1948), studying slope positions and their effect on nitrogen content of soils, concluded that although the soil on the steeper slopes is usually thinner, ". . . the other slope characteristics often upset this

relationship." Though the sites of steeper slopes often had thinner soils; reduced exposure due to north or east slope direction or to the site being in a cove, and greater length of slope could offset the effect of this factor entirely.

Similarly, other factors may modify the seeming consistent effect of topography. Douglass (1928), for example, found that growth of sequoias bore no clear relation to drainage. Beaufait's (1956) study of willow oak sites revealed entirely different effect of topography. In these bottom-land sites, the higher lands were more productive, and the effect was believed to be the result of improved drainage.

Slope

Length of slope. In general, great slope length above the site, signifying greater water availability from runoff and seepage, is a property of the better sites.

Slope percent. Slope percent itself, the degree of grade or inclination of the land has not proved to be a significant variable in all cases when it was studied.

Turner (1938) studying pine growing on the coastal plain soils of Arkansas found slope to be a significant factor, especially for slopes between $3\frac{1}{2}$ and 22 percent. Within this range the growth of pine was found to be poorer on steeper slopes. Working in Michigan with red and black oaks, Arend and Gysel (1951) found yields to be better on moderate than on steep slopes. Einspahr and McComb (1951) found a similar effect in oak in Iowa; site index decreased with an increase in percent slope.

Zahner (1958a), working in Arkansas, found a decrease of pine site index as slope percent increased. On the other hand, Gaiser (1951), working with white oak in Ohio, found that slope or pitch of land did ". . . not perceptibly influence site quality (p. 11)." Arend and Gysel (1951) found that oak yields were larger where degree of slope was less but that this effect was much less than that of soil texture or topographic position.

The effect of slope may be related to depth of the A horizon, and so the effect related to moisture-holding capacity as discussed under topographic position above. Norton and Smith (1930), studying forested loessial soils of Illinois, found that when slopes increased from 0 to 13 percent a decrease in depth of the A horizon from 24 inches to 9 inches occurred.

Exposure

The effect of exposure is probably mainly due to insolation differences and their effect on soil moisture. Cooper (1959) found in measuring microclimate on north and south facing slopes in eastern Michigan, that "soil temperatures were highest on south-facing slopes" and "soil-moisture levels were higher on north facing slopes."

Effects of exposure have been examined experimentally a number of times. Einspahr and McComb (1951), working with oak on loess-derived soils in Iowa, found site index to be 8 to 12 feet higher on north and east than on south and west exposures.

The effect of exposure is apparently closely dependent upon the species of tree. With yellow poplar, Schomaker (1957) found survival poorest on south slopes. Gaiser (1951) found white oak in Ohio grew

best on northeast exposures and poorest on slopes facing southwest and west. Potzger (1939), in Indiana, noted that south-facing slopes supported oak-hickory forests and north-facing slopes forests of beech and maple.

In areas of great relief the effects of exposure on composition are well known. There is also an effect on yield. As Auten points out,

> Cool, moist sites on this forest have been observed to give double the volume increment as did dry exposed sites on the same soil type. So pronounced is the effect of soil moisture that this factor alone often causes a change of tree type from the oak, chestnut on the ridges to the hemlock-birch, tulip poplar type in coves. (Auten 1930, pp. 56-57)

Records of actual climatic values on slopes of different exposures are not common. Byram and Jemison (1943) presented intensity of radiation for various north, south, and east-facing slopes as a fraction of the maximum; and they also presented the duration of radiation in hours for slopes of 100, 40, and 20 percent.

An interesting study of insolation was made by Boyko (1945). He studied yearly insolation at Jericho in Palestine, a region of dry climate at a latitude approximating that of El Paso, Texas or Albany, Georgia. Boyko presented graphical data for north-northeast compared with south-southwest exposures. On the former, insolation per square centimeter per year declined 2 kilogram-calories for each degree rise in slope (a 20 kilogram-calorie reduction for a ten-degree rise in slope). South-southwest exposures showed an increase of about two thirds of a kilogram-calorie for each degree increase in slope up to thirty degrees, after which it declined at a rate of about two kilogram-calories for each degree rise in slope. The decline was at the same rate as on the north-northeast slopes.

Microrelief

Microrelief is important because of its effect on depression storage, hence on infiltration. Depression storage is defined by Horton (1935) as:

> The volume of water, expressed as depth on the entire surface of a drainage basin, which is required to fill depressions, large or small, to their overflow levels. (p. 2)

Smooth, flat areas allow little depression storage. Rougher microrelief permits a more extended stay of water on the soil, and more infiltration.

Krumbach (1959) studied soil moisture and bulk density as affected by microrelief and found differences but rather small ones. He was investigating small-scale topography in flat bottomland areas, and used a 0.3-foot contour interval.

Soil Mapping Units

Any demonstrable correlation of soil series and types with site index classes would be useful and immediately applicable, since basic soil classification and mapping are reasonably well advanced in the region, and recent detailed maps are available for Benton, Decatur, Henry, and Henderson counties, Tennessee, and for the Ames Plantation. However, soil mapping units have proved of limited usefulness as an index of forest productivity because there is so much variation within classes.

A significant relationship between soil type and forest productivity has been looked for in vain by many investigators. Arend and Collins (1948) studying eastern red cedar sites in the Ozarks found that "no apparent important difference in occurrence, growth, and character of the natural stands examined could be associated with these different upland

soil types . . . (. . . soils derived from limestone, dolomite, cherty limestone, and mixtures of sandstone and limestone, and from sandstone alone . . . .)"(p. 510-11)

A few investigators have had more success in relating soil types or series to productivity. Notable among these is a recent study by Broadfoot and Krinard (1959) who developed a method of estimating site quality for sweet gum starting with a basic breakdown into ". . . standardized series and phase, after which sweetgum site index can be read from a table. . . ." (p. 1) Ray and Lawson (1955) found a significant relation between site index of four species of trees in the Ozarks and nine soil types based on depth, permeability and stoniness of surface soil. The relation is to soil "groups", generalized categories based on prominent soil characteristics.

Soil Structure

Soil structure is not often cited in site index work, probably because it is difficult to measure. Considering its importance in fertility, it should not be slighted. There are occasional references to its use. Diebold (1935) regarded it as one of the most important soil properties in the region he studied, northeastern United States.

Soil Moisture

The soil factor studied most frequently, and the one often kept in mind when many others are studied is the available moisture content or total water-holding capacity of the soil. As Lunt says (1939) of the second-growth stands of Connecticut,

Site quality is the resultant of a number of environmental factors,

> chief of which are those affecting the water economy of the tree; viz., available moisture, topography and depth of the soil. (p. 426)

Though the available moisture is of great importance to the growth of vegetation, and consequently to site index, it is possible that the effects do not always occur in the same way. It may be that it is not so much the water-holding capacity of the soil that is important but the rate the volume is refilled with water. Williams (1956) pointed this out. "It is probable that the maximum water-holding capacity of the soils is not as important as their rate of recharge. In soils of high permeability this may be rapid, but in soils of low permeability the recharge of subsoil moisture may occur only through deep cracks" (p. 138). In relation to this, Hills (1952) wrote of using pore pattern, as "the effective combination of the texture and structure of the soil . . . to indicate potential soil moisture within each local region . . . ." (p. 130). The horizon examined, however, would necessarily be interpreted with regard to the texture of overlying layers and its effect on infiltration.

That moisture availability is regarded as so important in site quality is because of the great use of water by trees and stands. Veihmeyer and Hendrikson (1927), studying French prune trees in containers, found an apparently consistent ratio of length of growth to water use.

Some of the great changes in soil moisture are due to the trees themselves. Douglass (1960), studying soil moisture distribution in a sixteen-year-old pine plantation, found it to be evenly distributed at the beginning of the growing season, but by the end of the growing season, the highest content was midway between trees. Lunt (1934), working with pines and oaks on Connecticut soils (Merrimac coarse sand) found that

moisture content values in percent of the moisture equivalent,

> . . . were lowest in the immediate vicinity of the tree base, and they increased in irregular zones with increased distance from the trunk, and with depth. In other words, while the highest percentage of moisture in the upper 4 feet of soil was found at about 1 foot, the highest relative wetness values were found at the 3- or 4-foot levels. (p. 703)

Recent studies have given us much information about the use of water by stands of timber. We know that such use can be very high. Moehring (1960), for example, concluded after studying data for Arkansas that ". . . well stocked stands of pine or hardwood will use up to 8 inches of water per month during the summer months if the water is available . . ." (p. 7).

Lull and Axley's (1958) work in the Coastal Plain sands of New Jersey indicated that water use is the same for different types of timber. In the Pine Barrens of this area, soil moisture measurements ". . . indicated that stands of shortleaf pine and oak scrub used about the same amount of water at about the same rate from the upper 5 feet of soil" (p. 17).

Just how generally this can be applied is not clear. It may be that these two vegetation types have similar root distribution, for apparently their effect on the soil moisture is similar. But forest vegetation may act in another way. Zahner (1958), from his studies in Arkansas, found that when the understory was eradicated from plots, water loss in the summer was not as great. As long as moisture was not critical, water use from all types of vegetation studied was about the same. "By July, however, as the soil dried, moisture levels in plots with no hardwood understory were more than 50 percent greater than in plots

with the understory present." (p. 183)

This has been found before. In 1928, Adams reported that jack pine growth was retarded by decrease in the amount of available soil water and root competition. And later Metz and Douglass (1959) concluded that the depleting effect of roots was especially obvious in the "surface 66 inches of soil" (p. 11).

Although as a general rule productivity increases with increase in soil moisture, it may be adversely affected by water supply so great that it interferes with aeration. This is well illustrated by Kittredge's (1938) data for aspen in Minnesota and Wisconsin. He found that sandy surface and C horizons had different effects depending on whether the site was xeric or hydric. In xeric habitats sandy horizons decreased site quality, but in hydric habitats sandy surface horizons improved site index, presumably because they improved drainage.

Shipman and Rudolph (1954) found in Michigan that growth of young poplar was much better on sites where conditions enhanced all aspects of the moisture regime. Husch (1959), studying height growth in white pine in New Hampshire, attributed differences in height growth on the four plots to ". . .differences in available moisture. Other environmental characteristics were very similar on all plots."

Studying western mountain vegetation types, Pearson (1920) concluded the most significant soil characteristic relative to their distribution was available water. Gaiser, studying white oak in Ohio (1951), found that site index increased with total available moisture in the A horizon. Shipman (1953) found that soil moisture through the growing season was the

". . . principal limiting factor contributing to the marked differential height growth of plantation-grown tulip poplar" (p. 129).

The actual immediate effect of water in limiting or enhancing growth is not well understood. Although water plays a part in the photosynthesis reaction its roles in the solution of nutrients in the soil and in the elongation of cells are probably much more limiting. Wiersum (1957) has reported the studies of Visser and Goedewaagen as presenting another facet of water's role in plant growth. They ". . . noticed that roots of flax could penetrate a dense subsurface layer in a loam soil early in the spring when the soil was still moist and plastic." When later this layer hardened because of desiccation, downward root growth was severely restricted (p. 84 f.).

One of the very common measurements made in soil studies is that of depth to mottling. Mottling is accepted as a reliable indicator of imperfect aeration in the soil. Thus a soil with strong mottling or with mottling close to the surface is regarded as one in which drainage and aeration are poor. Aeration is intimately associated with soil moisture, since they are complementary functions of the pore space in the soil. Barnes and Ralston (1955), working with slash pine (Pinus elliottii Engelm) in Florida, found site index increased with mottling depths up to 30 or 40 inches. At greater depths site index decreased slightly.

Generally, growth is better--site index is higher--on sites where drainage is good. The association of high site index and adequate drainage is commonly made. Diebold (1935), for example, noted that site index was better on well-drained soils. Aird and Stone (1955) found that growth of European and Japanese larch in New York State was ". . . most closely

related to drainage class, and to depth of soil above a layer restricting root development." (p. 428). Growth differences are most noticeable when sites of adequate drainage can be compared with those where the drainage is poor. Growth is generally less on "moist" and "wet" sites. This may even be qualified, as it was by Zahner's work, when it was shown that productivity could be improved by increased drainage only if the drainage was not increased too much--was not excessive. This is the reason that ridges are regarded as poor sites. As Zahner noted (1958a) site index was ". . . better on areas with just adequate drainage than on flat areas with no drainage or on slopes with good drainage."

A relatively new idea in the interpretation of drainage effects was recently introduced by Applequist (1960). He suggested that flooding may not be a condition that swamp species simply tolerate between more favorable mesic conditions.

> The somewhat common belief that swamp species "tolerate" flooding but actually make their best growth under well-drained conditions deserves critical analysis. . . . It is suggested that the hydrophytic swamp blackgum and tupelogum may not only tolerate but may literally thrive under flooded or near-flooded conditions. (p. 62-3)

Hosner (1959) cited the frequent presence of species ill-adapted to saturated soils (pin oak, hackberry, and cherrybark oak) ". . . on wetter sites than cottonwood and sycamore . . ." as evidence that effects other than flooding were involved in species determination on these sites.

The true answer may be somewhat like that which Smith (1957) gave for cottonwood on alluvial soils in British Columbia:

> Cottonwood grows poorly where water is stagnant; flooding, with fast, moving water that is rich in oxygen and nutrients, speeds growth. Stagnant pools. . . shorten the effective period of growth. . . . Fine

> sediments . . . may inhibit aeration, slow percolation of summer rain, and reduce growth . . . Ridges of sand that have been cut off from the main water channels are likely to suffer from drought in dry summers but sand ridges along main stream channels support many excellent stands of cottonwood. (p. 580)

Relative survival of various species under drainage stress was studied in seedlings by McDermott (1954). He found that after saturation of the substratum and later drainage ". . . river birch and red maple seedlings recover very rapidly, sycamore rapidly, and American elm and winged elm at a moderate rate." Saturation intervals up to 32 days did not seem to affect alder seedlings and their growth was actually improved by short intervals of soil saturation. Potzger found (1939) that lowland forests were invaded by beech ". . . as soon as soil is elevated ten to twelve inches above the water table."

Generally, internal drainage is thought to be primarily an effect of soil texture--sandier soils are better drained than siltier soils even though their over-all productiveness may be limited in other ways. Broadfoot and Krinard (1959), studying sweet gum sites, used internal drainage as one of a set of factors in estimating productivity of sites in the Mississippi River floodplain. In such low-lying areas the adverse effects of poor drainage are particularly striking. Where drainage is deficient, site quality is poorer. Diebold (1935) found this to be true of native hardwoods on glacial soils in New York. Kittredge (1938) found it in aspen in Minnesota and Wisconsin. Moisture increase improved site conditions except where drainage was deficient. Under deficient drainage, site index decreased with increase in moisture. Donahue (1940), studying conifer plantations in New York, found sites to be poorer where internal drainage

was poor, and Stone, Morrow, and Welch (1954) associated stunting and dying of red pine in plantations with impeded soil drainage.

Soil conditions can be improved by artificial drainage. Pruitt (1947) found that drainage at pocosin margins affected the height growth of trees. Wilde and Pronin's data (1949) show that on silicious gley sands in Wisconsin, site index of quaking aspen increased with increases in depth to the water table to 32 inches. Below that, as depth to the water table increased, site index increased.

Soil Texture

As a soil factor affecting site index, soil texture is regarded as of great importance. The probable reason for this is that soil texture has a fundamental effect on moisture content of the soil:

> In coarse-textured soils the moisture tension changes relatively little from field capacity almost down to the wilting percentage and at that point changes rather precipitously to permanent wilting percentage. Moisture tension-moisture content curves for finer textural grades of soil do not exhibit such a sharp break and indicate that water is withheld from plants with appreciably greater energy over the lower part of the range than over the upper part. In terms of energy relationships the water in such soils becomes gradually less available as moisture content decreases from field capacity to wilting percentage. (Kozlowski, 1955, p. 509)

In view of the importance of soil texture in soil water regimes it is not surprising that site index has often been significantly related to textural values. On upland sites the textural values that improve site index are those that improve water supply to the stand. Arend and Gysel (1951) found that in soils of southern Michigan the yield of red and black oaks on flat land in general increased with clay content. Specifically, though, they found that,

> . . . oak yields are low on light sandy soils and upper slopes where moisture can drain away. However, on lower slopes where drainage is impeded and the soil moisture can be replenished from above, the yields of oak are high regardless of the soil texture.

The general increase of site index with increase in the proportion of finer soil particles has been reported by numerous investigators. In 1929, Haig published a study of red pine in Connecticut showing an improvement of site as the silt and clay percent in the A horizon increased. Zahner (1958a) found in Arkansas that the site index of loblolly and shortleaf pine increased with the increase of silt and clay content of the subsoil. Hickock et al. (1931) found that site index of red pine in Connecticut was correlated with increases of silt and clay in the soil up to 25 percent. Broadfoot and Krinard (1959) found that sweet gum sites were better where clay content was higher. Applequist (1960), also studying hardwoods on alluvial soils, found that site index was directly related to the percent clay in the least permeable layer of the soil. An unpublished report of Allen (1959) of T.V.A. on a cooperative soils investigation in north Alabama and Mississippi has presented a correlation of site index of loblolly and shortleaf pine with increase of clay in the subsoil. Stoeckeler (1948) found that aspen in the Lake States showed site increases with increase of silt and clay content of the A and B horizons. Barnes and Ralston (1955) found site index of slash pine to increase with the silt plus clay content of the heaviest soil horizon. Increases in silt-clay content up to twenty percent caused improvement in site index. Above that there was no added effect. Shipman (1953) found that tulip poplar height growth was associated with the amount of fine clay. The Southern Forest Experiment Station's Sewanee Research Center (1959) has reported a similar relationship for loblolly pine on the

Cumberland Plateau. Dingle and Burns (1954) found site index of shortleaf pine on loess-derived soils to be associated with the percent clay in the A horizon.

It is apparent that texture of the A horizon and of the B horizon have different effects. In classifying the productivity of pine sites in Arkansas, Zahner (1958a) found the texture of the subsoil effective. In addition, for azonal soils he used the texture of the surface layer, and for zonal soils, the thickness of the surface layer. He found that in azonal soils site index of loblolly pine (there was not much shortleaf on these sites) decreased with the increase in silt content of the surface soil but increased with the increase of the silt plus clay content of the subsoil.

This relation between the horizons was marked by Smith (1957) who studied the growth of cottonwood in British Columbia on alluvial soils. He maintained that "at least 18 inches of loam or heavier soil are required for good growth if soil is underlain by gravel." It is not certain that this is a technical usage of the word "loam", but it is apparent that Smith was speaking of the increase of the finer particles in the soil.

Westveld (1933), studying uneven-aged stands of northern hardwoods, found sandier soils better than silty soils, and site index decreasing when soils were shallow or stony or when subsoils were clayey or consisting of coarse sand or gravel. Turner (1938), studying Coastal Plain soils in Arkansas in relation to pine growth, found that growth was better where the texture was looser, and concluded that this was because of better aeration and drainage.

Increase in clay content as related to increase of site quality was reflected in Young's (1954) findings. He found that site index of spruce (no species was indicated) increased with the increase of the imbibitional water value of the A horizon. This was a reflection of soil textural differences, since imbibitional water values are greater where textures are finer.

Barrington (1930) discusses a method that may be effective in rating soils in Tennessee bottomlands, particularly those where soil is immature and is made up of layers of silt and sand. He used what he called the "texture index" in evaluating forest soils in Burma. He plotted texture indices downward from the ground surface using the indices as the horizontal scale and depth as the vertical scale. Lines drawn between the points showed a "profile" characteristic of the soil. Barrington maintained that the best soil would not have sharp peaks; in other words, would not have great abrupt changes in texture. His texture index was obtained by computing surface area weighted by the percentage of the classes of particles in it for each depth:

> Thus 10 per cent. of clay gives a relative surface area of 7.92, 5 per cent. of fine silt 0.79, 7 per cent. of silt 0.28, 20 per cent. of fine sand 0.16, 25 per cent. of coarse sand 0.04, and 33 per cent. of fine gravel 0.02; giving a textural index number of 9.21 for a sample containing those percentages.(p. 146)

Using this system, Barrington obtained "1.09 for a gravel and 42.37 for a calcareous clay" (p. 146).

Applequist (1960) used a texture-depth index in testing the attributes of alluvial soils. This was ". . . the ratio of the silt-plus-clay content of the least permeable horizon to the depth to the least permeable

horizon." This figure, however, was not as effective in site prediction as the separate sand or clay percentage.

Soil Depth Measurements

Increase in site index has often been found to be related to an increase in depth of the soil or of one horizon. Jackson (1960) pointed out that Coile and Schumacher, Ralston, Gaiser, and Metz all found site index to be correlated with some measure of effective soil depth.

Often this has been the depth of the surface soil. Zahner (1958a) found this to be true of loblolly and shortleaf pine in Arkansas. Site index increased with the thickness of the surface soil (A horizon) up to 18 inches. In north Mississippi and Alabama, a cooperative study by the Tennessee Valley Authority (Allen, 1959) yielded similar results.

The same relation was found by Gaiser (1951) for white oak on the gray-brown podzolic soils of southeastern Ohio and by Dingle and Burns (1954) for shortleaf plantations on silt loams derived from loess in Missouri.

The thickness of the entire solum has proved an effective indicator in some areas. Diebold (1935) found site index of hardwood on young glacial soils was better where soils were deeper. Einspahr and McComb (1951), working in Iowa with oak, found site index to increase with an increase in the depth of the soil "to unconsolidated bedrock." Similar data were found by Kittredge (1938) for aspen in Minnesota and Wisconsin. When the rocky substratum was at shallow depths, site index was low.

Depth to a change to a finer texture was found to be directly correlated with rate of height growth of slash pine by Barnes and

Ralston (1955) in Florida, but the same characteristic used on alluvial soils by Applequist (1960) was not as effective.

When measurements are carried far enough, it is found that at some point added increases have no further effect. Zahner's report on loblolly pine (1958a) showed an increase in site index with increases in thickness of the surface soil, but only up to eighteen inches. Beyond that depth site index did not increase. In white pine and spruce, Young (1954) found that increase in the depth of the A horizon reduced site index.

Alluvial Soils as a Special Class

Bottomlands form a large proportion of the forest lands of the study area, and they are important not only because of their extent, but also because more growth of timber and timber of higher quality occur on these lands. Soils there differ from upland soils, and it is possible that their examination may require special techniques.

The difference in approach is well illustrated by the conclusions of Smith (1957) who studied growth of black cottonwood (*Populus trichocarpa* Torr. & Gray) on alluvial soils in British Columbia and found no single soil factor was a satisfactory indicator. "Many combinations of texture, porosity, depth, depth-to-water-table, and nutrient status. . . ." (p. 580) were associated with good site index, but he considered no one factor by itself consistent enough.

Smith felt that the special characteristic of alluvial soils was their impermanence. "Site changes," he wrote, "every time the land is flooded." The soils most recently created by deposition were poorest in site quality. The best soils were those of fine texture, ". . .

topographically higher than average but still subject to flooding in extreme high water" (p. 580). This same association of fine soil and periodic abundance of water as characteristic of good bottomland sites was likewise made by Applequist (1960).

In his field guide to pine site classification, Zahner (1957) made the separation of zonal and azonal soils his primary division. Within the classes resulting, soils were graded by textural class of the subsoil; slope; and, for the zonal upland soils, thickness of the surface soil, but for the azonal upland soils, textural class of the surface soil. This is not a difference in approach, but simply two predictive formulas employing different (in part) variables.

More pertinent is the work of Broadfoot and Krinard (1959) on sweet gum sites in the Mississippi valley and Applequist (1960, see above) on alluvial lands of the Atlantic Coastal Plain. The essential difference is not in approach but in results and their explanation.

D. OTHER FACTORS AFFECTING SITE

Stand Effects

The primary stand effect is that of competition. It is in the effort to avoid the effects of competition that only dominant trees are used in site index determination. Competition resulting in suppression retards the height growth of the suppressed tree so that the height over age value is not a reliable index of site potential--the tree is not free to grow as affected only by the other environmental factors.

McIntyre (1933), in studying yield in hardwood forests in Pennsylvania,

accumulated data on comparative height growth of dominants alone, dominants and codominants, and finally, all trees of a stand. This was done in an even-aged oak forest containing a small amount of red maple and hickory. From the curve he produced (p. 6), differences in height are as follows:

	Site index at 50 years	100 years
Dominants	64	89
Dominants and codominants	60	85
All trees	52	62

The inclusion of trees other than dominants has a notable effect, so the relation of the tree to the surrounding stand must affect site index greatly.

In all-aged or uneven-aged stands the danger in site index work is that a tree may have been suppressed. This could occur in even-aged stands as well, but it would be unusual. In uneven-aged stands it would be commonplace.

Kittredge and Chittenden (1929) measured a number of trees in oak stands in northern Michigan and produced curves of diameter and height growth of dominant trees and suppressed trees. At 20 years of age the suppressed trees were seven feet tall and the dominants 16 feet, at 50 the suppressed 34 and the dominants 51; and at 80 years the suppressed were 50 and the dominants 74 feet tall.

Site Factors and Species Composition

Water-soil relations seem to have the most striking if not the greatest influence on species composition of forests. Their most obvious

effects are those associated with differences of slope. McQueeney (1950) found in Indiana that the species on north and lower slopes were more of the mesophytic type while those on south and upper slopes were more xerophytic. Pearson (1920) in western mountain types concluded that the most significant soil characteristic relative to vegetation distribution is available water. This recalls Warming's doctrine that "All plant associations are determined primarily by the water content of the soil" (quoted by Potzger, 1939, p. 224).

Such relations are very apparent in regions of great relief. In the Great Smoky Mountains, for example, pine is common high on southerly slopes, which are dry; while on the terrace-like stream-edge lands hemlock and rhododendron are more frequent.

Though he was writing of grassland vegetation, Williams' (1956) statement of the relationships is a representation of the probable causes. He noted that species composition appeared to be greatly influenced by water-soil relationships, and continued: "redistribution of rainfall is affected by textural and structural differences between soils. A xeromorphic flora develops where run-off commences and a hydrophytic flora where it ends." (p. 138)

In west Tennessee the relief is not extreme but there is nonetheless a segregation of species associated with topography. One forester of experience in west Tennessee states that yellow poplar is found more on north and east slopes; white oak usually on north slopes; that southern red oak is usually found on south slopes as is scarlet and black oak.

Differences are not confined to the uplands. In the bottomlands

cherrybark oak is found more on the ridges; and on the flats, slightly lower, are willow oak and water oak. Thus even on alluvial land different zones of tree composition and growth may be distinguished. In a study of the growth of poplar, the Food and Agriculture Organization of the United Nations (1958) distinguished the following zones on alluvial land:

water edge: willows, poplar, and sycamore in dry years.

regularly flooded: willow and poplar.

occasionally flooded: ash, maple, sycamore, Virginia creeper, boxelder.

"fresh" sites: in Europe sycamore, in America Liquidambar.

dry sites: hornbeam, birch, cherry; in Europe Norway maple, white poplar.

marshy zones: alder.

Soils and species composition. Some investigators have had good results in attempting to correlate plant growth and soils, and some have not. These relations have been praised by some and condemned by others as misleading.

Turner (1937) made broad groupings of Arkansas soils and listed tree species associated with each. Snow (1956) listed data of survival of conifers and hardwoods on Coastal Plain soils. Dale (1958) correlated tree species in Arkansas with underlying rocks and Einspahr and McComb (1951) found stand composition related to soil series and topography.

Read (1952) in the Ozarks correlated species with various soil parent materials and ranked the species by apparent dominance index, as follows:

<u>Boone chert</u>

1. Black oak
2. White oak
3. Flowering dogwood
4. Mockernut hickory
5. Blackgum

<u>Boone limestone with cherty surface soil</u>

1. Northern red oak
2. White oak
3. Black oak
4. White ash
5. Winged elm

<u>St. Joe limestone</u>

1. Eastern red cedar
2. Northern red oak
3. Winged elm
4. Chinquapin oak
5. Shagbark hickory

<u>Newton sandstone</u>

1. Black oak
2. White oak
3. Blackgum
4. Flowering dogwood
5. Ozark chinquapin

These were on 20-30 percent slopes of a north to northeast exposure.

One objection to the use of plant indicators is presented by Diebold (1935). He maintained (p. 642) that on limestone soils plant indicators might be reliable, but on other soils "the same flora tends to occur irrespective of the degree of subsoil drainage, sheet erosion, and inherent productivity."

In the early days in the United States land was often evaluated from the type of tree growth on it. This practice rests upon the belief, as stated by Hilgard (1906), that ". . . <u>the natural vegetation of any tract represents</u> the best adaptation of plants to soils . . ."(p. 487) as developed over thousands of years. If the original plant cover has not been disturbed, differences in species should indicate differences in soils.

Hilgard apparently found the closest correspondence to be between vegetation differences and the boundaries of geological formations. His map (p. 490) of the soil belts of northern Mississippi was developed using such relations.

One of the most complete statements on the evaluation of land from

the type of tree growth on it is that of Killebrew (1884), writing of the culture of tobacco. Killebrew held that hickories, white oaks, tulip poplars, walnuts, maples, and beeches indicated good land; and post oaks, scrub oaks, blackjack, chestnut, chinquapin and pine indicated poor land. He also added, however, that these species could occur almost anywhere and that,

> . . . one must judge by the predominance of species and by the character rather than by the kind of growth, and especially by the undergrowth. The timber test for land is of little use to the inexperienced, while it is of great value to the experienced eye. (p. 113)

Some soil classification schemes based on tree species were rather elaborate. Thus Hulbert (1930) listed a number of oaks as soil indicators. When accompanied by hickory they were said to indicate good soil, and when accompanied by pine, poor soil. The shape of willow oak or post oak was thought significant. If short and rounded, the soil was poor; if tall and stately, the soil was good. Nut-bearing trees in general indicated good soil, but pignut, mockernut, and whiteheart hickories (the "disappointing hickories") indicated poor soil.

While some of these relationships do hold, they cannot be relied upon for evaluations of precision. For this reason it is probable that the scheme set forth by Hulbert is too intricate. The results could not be expected to be as precise as these procedures suggest. As Shantz (1911) says, it is not the presence or condition of any one species; but the state of the plant cover as a whole that should be relied upon.

There is apparently some relation of species composition to drainage. Applequist's findings (1960) may be most pertinent in this regard. Another instance of this was reported by Fritts and Holowaychuk (1959). They studied

beech in Ohio in associated sites of depressions, lower slopes, and low ridges and found the species most abundant on the lower slopes and restricted on the depressions due to poor aeration. On the low ridges beech had deeper roots and was not easily harmed by drought but moisture was less than on slopes so basal area was lower.

Moore (1959) demonstrated an interspecific effect in eucalyptus. Although each species grew slightly best on its own soil, relatively little difference in growth and yield was shown by a single species in soil from a stand where it was dominant and from a stand where another species was dominant. In mixed stands the tree native to the soil did significantly better (p. 734).

As far as the relation of species composition to site index, or the effect of different site indices upon species composition, Weitzman and Trimble (1957) found that the proportion of oak decreased with increasing site index. Red oak increased with the site index while chestnut oak and scarlet oak decreased with an increase of site index. The variety of species increased as site index increased (p. 6-7).

The relationship of forest composition to site was explored by Bourdeau (1954). He studied segregation by oaks of the Piedmont into groups related to site and found that the poorest sites usually supported post oak and blackjack oak; the intermediate sites post oak and white oak, and the best sites a mixture of white oak, northern red oak, and black oak. He concluded that species of the good sites (northern red oak, scarlet oak, and white oak) are absent from poor sites because of susceptibility to drought and that poor site species (post oak and blackjack oak), because

slow-growing and intolerant of shade, cannot survive the competition of the dense stands on the good sites.

CHAPTER III

REGIONAL BACKGROUND

This study was conducted on the Ames Plantation, a large farm in west Tennessee fifty miles east of Memphis, in that section of the state lying between the Tennessee and Mississippi Rivers. In this area a portion of the Coastal Plain forms an embayment or tongue northward which is bisected by the Mississippi. The western part of the state of Tennessee extends into this embayment.

The Ames Plantation is an 18,000-acre farm in Fayette and Hardeman Counties, Tennessee, about eight miles north of the Mississippi state line. The Plantation covers an area approximately 6 miles by 10 miles in extreme dimensions. This land was opened in 1818 after purchase from the Chickasaws, and some of the Plantation timber dates back even earlier.

Low-income farms and poor living conditions are characteristic of the area. Neighboring towns are small. The dominant local occupation is farming. Some forestry activities are carried on, and these will increase, since a pulp mill is being established about fifty miles to the east. The underlying Coastal Plain deposits furnish sand that has been marketed in the area. The same source yields clays which once were mined locally, and there have been some attempts at reviving this industry.

Recent changes will probably be far-reaching. A plastics factory has been installed at Grand Junction, and a number of local people are employed there. The nearby pulp mill under construction will certainly affect timber prices and employment in the area.

The lands of the Plantation were massed into a hunting preserve by the late Hobart Ames, a wealthy industrialist of Massachusetts. During Mr. Ames's life the Plantation was not managed for efficient production. The object was to keep everything as it was, and to preserve the course of the National Field Trials (for bird dogs) which were held there each year. In the nineteen-fifties a bequest of Mr. Ames's widow made the Plantation available to the University of Tennessee for research. The present study is an example of the type of work possible on such an area.

At the present time, in addition to serving as the home of the Field Trials, part of the Plantation is being managed as a cattle breeding farm. This is in part a heritage from the prize purebred Aberdeen Angus herd that was on the Plantation in Mr. Ames's time. An innovation is the program of tenant farms developed by the University on small subdivisions of the Plantation. On these farms agricultural programs based on many crops relatively uncommon in the traditional local agriculture are being tried.

The original labor force on the Plantation consisted predominantly of Negro share-croppers, or wage-hands of the Plantation itself who were also part-time tenant farmers.

A. ENVIRONMENTAL FACTORS

<u>Climate</u>. This is cotton country, with hot summers and mild winters. Monthly mean temperatures range from a winter average of about 40 to a summer average of about 80 degrees Fahrenheit. Rainfall averages about fifty-three to fifty-four inches a year and summer droughts are not

uncommon. Most of the rain falls in the early spring.

Topography. The region is a portion of a highly dissected plain sometimes called "the plateau slope" (Safford, 1884) about 80 miles wide from east to west. Drainage is to the west. The over-all slope is gentle but erosion has made many gullies with precipitous sides.

The maximum elevation on the east side of the Ames Plantation (616 feet) is about 100 feet higher than that in the west, ten miles distant. Local relief at the east and west sides is about 100 feet.

The plain is highly dissected by stream and gully erosion. Some broad upland areas are present but often eroded from the sides. There are a great many ridges produced in this fashion that are flat on top and skirted by precipitous (though short) slopes of loess ending in the gradual lower slopes of the Coastal Plain sediments.

B. GEOLOGY

Schneider (1947) described the Mississippi Embayment as a "downwarped, downfaulted trough in Paleozoic rocks, in which have been deposited sediments ranging in age from Cretaceous to Recent."

The region under consideration is a shallow, elongated, bay-like depression or trough with the Mississippi River flowing through its central portion. At the base are Paleozoic rocks upon which the sandy Mesozoic and Cenozoic sediments of the Coastal Plain have been deposited. Overlying these is a layer of loess 30 to 100 feet thick in the west at the bluffs of the Mississippi River and thinning eastward to local extinction before reaching the Tennessee River. The loess is the "brown loam" of Hilgard

and others (Wascher et al., 1948, p. 390).

The Holly Springs sand of the Tertiary system underlies the loess in the Ames Plantation area. These sands, some fine and some coarse-grained, ranging from orange to red to yellowish brown and gray are exposed when erosion washes away the loess. Interspersed with them are clay lenses which vary in extent and thickness (Whitlatch, 1940). The Holly Springs sand is 450 feet thick in Fayette County and 250 feet thick in Henry County, Tennessee, about 100 miles to the north (Whitlatch, 1940).

C. SOILS

The soils of the Ames Plantation belong to the Gray-Brown Podzolic Great Soil Group. They are derived from loess overlying Coastal Plain materials at varying depths. In old accounts the soil of the region is referred to as a "mellow, siliceous loam" and is generally regarded as good soil for farming. But as Safford (1869) says, "as the soil is easily tilled, so it is easily washed away" (p. 431). This still fittingly characterizes the soils of the area.

The soils of the Ames Plantation were classified and mapped by Overton, Harmon, Elder, and Epley (1951). The report grouped the soils by gross topographic differences into soils of the uplands, of terraces, or of bottomlands. Soils in upland drainageways (colluvial soils) were also separately considered.

Soil series of the uplands are, in order of decreasing drainage, Memphis, Loring, Grenada, Callaway, and Henry. These soils are silt loams derived from loess. The latter three develop pans which restrict roots

and the movement of moisture. There is often a weak pan in Loring.

Lexington is a brown silt loam resembling Memphis except that the sandy material beneath it is closer to the surface. Ruston and Susquehanna are Red-Yellow Podzolic soils derived entirely from Coastal Plain sediments.

"Colluvial" soils in the drainageways are Tigrett, Briensburg, and Dyer, following the terminology of Overton et al. (1951). These units are now correlated as local alluvium phases of Vicksburg, Collins and Falaya, and Waverly, respectively.

Terrace soils from silty alluvium are Lintonia, Richland, Olivier, and Calhoun. The latter two have pans, Richland a slight pan. Terrace soils from sand and silt alluvium are Dexter, Freeland, and Chattahoochee.

Vicksburg, Collins, Falaya, and Waverly are bottom soils from silt; Hymon, Ina, and Beechy from silt and sand, and Tombigbee from sand.

Overton and his colleagues (1951) also used several "miscellaneous land types" to cover special soil forms: in the uplands, "gullied land" and "gully wash", and in the bottoms, "sand overwash." Gully wash and sand overwash are recent deposits, the latter the result of flooding.

D. VEGETATION

Classification by Plant Geographers

The vegetation of the region is hardwood, or predominantly hardwood. There are some stands of pine in the area but they are not common. The area is generally placed in the deciduous forest region. See, for example, Livingston and Shreve (1921) and Transeau, Sampson, and Tiffany (1953).

Braun (1950) considers it part of the western mesophytic region of the deciduous forest.

Historical Accounts

A detailed picture of the local vegetation may be obtained from Safford's (1884) agricultural description of counties in the region. The Plantation straddles the line between Hardeman County and Fayette County to the west. Of Hardeman County, he said,

> The growth of the chief soil, the silicious loam of the uplands, is in the more level parts of Hardeman, red, white, and post oaks, hickory, walnut, wild cherry, dogwood, red-bud, and in the western part black-jack oak. In the more hilly portions, the southwestern, southern, and northeastern, black-jack and Spanish oaks (probably *Quercus falcata* Michx., cf. Hilgard 1906, p. 502) and chestnut are found. The growth of the lowlands is beech, white and red oaks, sweet and black gums, poplar, hackberry, red-bud, cane, and others. Areas of yellow pine occur in the northeastern and eastern portions. Cypress is met with along the streams. (p. 55)

A description of Fayette County by the same author described upland forest growth as "oak, walnut, poplar, and hickory, often of great size; of the bottoms, white and overcup oaks, beech, red and black gum, birch, and along the streams, cypress" (p. 54).

Vegetation Pattern on the Ames Plantation

The forests of the Ames Plantation most often occur in small patches. The large, smooth areas of land are farmed; the areas between are usually forested because they are drainageways and include gullies with steep slopes and irregular land features impossible to farm with machinery. Broad areas in the bottomlands have been left in forest because they are too low or wet or subject to washing-in of material from eroding lands above.

Forests on all of these lands may be first divided on the basis of

stage of development. Some of the upland areas, particularly around healed drainage channels, are in early stages of succession. The forests are not mature stands but assemblages of many light-seeded, fast-growing species such as sweet gum or elm.

Other forests are fully developed. These are the stands of red oak or white oak in the uplands and sweet gum in the bottomlands. Forests in the area fall quite naturally into these two groups--those of the uplands and those of the bottomlands. The upland forests contain a great number and variety of oaks (there are about twelve species present) chief among which are black oak (*Quercus velutina* Lam.), southern red oak (*Q. falcata* Michx.), and white oak (*Q. alba* L.). Some scarlet oak (*Q. coccinea* Muenchh.) also is found on slopes where moisture may be critical, especially on ridges and south-facing slopes. Blackjack oak (*Q. marilandica* Muenchh.) also, is often present on these sites. Eastern red cedar (*Juniperus virginiana* L.) is another common upland tree. In the past, chestnut (*Castanea dentata* (Marsh.) Borkh.) was an occasional tree in this area, and dead trees of this species are still infrequently found.

Growth in the river bottom is much greater, and trees there are much more impressive in girth and height. Sweet gum (*Liquidambar styraciflua* L.) is probably the commonest tree. Often present is tulip poplar (*Liriodendron tulipifera* L.), and perhaps less frequently, cherry-bark oak (*Q. falcata* var. *pagodaefolia* Ell.). Although it is found along the Wolf River a few miles to the west, cypress (*Taxodium distichum* (L.) Richard) has not been encountered on the Plantation.

Forest Growth

Forest growth in the region should be good. In a U. S. Forest Service publication issued in 1955, west Tennessee was said to have the best timber growth of any area in the state. This was 208 board feet per acre per year (Sternitzke 1955, p. 29).

According to Ewing (1956), the cruise of the Ames Plantation forest land by Kring and others showed growth of about 182 board feet per acre per year. Only about half of this was merchantable, the remainder being in poor quality trees of little value. Growth could be much increased, perhaps up to 200 to 400 board feet per acre per year (Ewing 1956), but this will take improvement in quality and increase in growing stock.

CHAPTER IV

PROCEDURES

A. FIELD AND LABORATORY METHODS

Reconnaissance Survey

A reconnaissance survey was first undertaken to promote familiarity with the timber types, and to allow accumulation of information on woodland features associated with site index.

Since the woodland had been disturbed relatively little for a long time it was thought that natural timber types developing on the land might be related in some way to productivity. Inasmuch as blackjack oak and post oak occur on poor sites and cherrybark oak seemed to be present on good sites their presence or absence might be used as a guide to productivity of a site. To obtain more information on this, several reconnaissance surveys were made wherever extensive areas of forest could be found. No attempt was made to map all species present; but only those which seemed to occur in rather continuous patterns. Trees such as mulberry (*Morus rubra* L.), for example, which occurred singly and were often absent over great areas; or sassafras, which occurred mostly in young groups of sprout origin, were ignored.

The size of the area and the choice of the critical species, the maturity or development of the vegetation, and those abrupt changes in vegetation due to topographic irregularity, all were considered to affect composition mapping. Moreover, since only a certain maximum number of trees can occupy one site, care had to be used to prevent giving too much

importance to the absence of any one species. This illustrates the problem in the use of plant indicators; too much emphasis may be placed upon the presence or absence of one species.

If soil and vegetation maps were to be compared, it was considered that the minimal size area to be mapped would have to be about the same size as the soil mapping units. On the 1" = 1320' map (scale 1/15840) the smallest mapped soil unit was about one-sixteenth inch across. Therefore an area 82.5 feet across (1320/16) was the smallest area of composition requiring mapping on the ground. Actually there were few areas a sixteenth of an inch across on the map <u>both</u> ways. Areas mapped by Overton et al. as this size were usually at least three times this in length and then often were extensions from larger areas.

It was found that much of the work of this sort could be done using colored pencils on aerial photographs of the region. With time and great care individual trees could be picked out on the aerial photograph. In this fashion, theoretically, a complete species composition map could be made by labeling crowns on the photo from field examination of individual trees. The purpose here was simply to establish on the photo the patterns to test them against topography, or soils, or whatever characteristic of the region could be mapped.

Study of Individual Trees

In addition to the extensive reconnaissance phase of the study, a more precise set of data was obtained by examining intensively trees and their sites at many locations on the Plantation. Sampling was limited to trees in the forests of the Ames Plantation.

At seventeen scattered sites within this area, transects were run sampling only dominant trees of five species: southern red oak, white oak, tulip poplar, cherrybark oak, and sweet gum. Sampling sites were selected by examining aerial photographs for forested areas of uniformity. All data were obtained by examination of individual trees at their sites and the measurement of the trees themselves and the factors of the site thought to have a measurable effect on the tree.

To test the possibility of using species composition or some aspect of it as an indicator of site, part of the data recorded at each tree was on the composition of the stand in which the tree grew. This was stratified by topography so that only the composition of the site on which the subject tree was located was recorded.

Bottomland sites were sampled by 5-chain sections. The five species studied were sampled, if present once within this distance along the sampling strip. At the end of the five chains sampling was begun again. In the hilly areas of the uplands, the boundaries of the sampling unit were determined by topography. When passing from one topographic division to another, from a ridge to a slope, sampling was begun again. If white oak was present on the ridge it was sampled only once, the first white oak encountered being selected unless defective. If, upon leaving the ridge and entering the slope, more white oak was encountered, it was sampled in this new division.

In any unit the first tree encountered within a strip approximately 5 chains wide was chosen providing it had no defect that would interfere with growth (forked and hollow trees were rejected). If two trees were

equally worthy and had like priority, the largest or tallest was chosen.

Data were obtained on tree growth and other characters of each tree and on site conditions for each tree. Growth data were derived from cores made at selected heights allowing the construction of a height curve for each tree. Other tree data taken were crown class, grade, merchantable height, and stem form. Data taken on the site were dominance relative to shade, map unit (in the classification of areas by critical species), microrelief, slope, topographic position, area draining to the tree, and a number of soil properties.

The last item was based on an examination of the soil at several points within 5 or 10 feet of the tree. The upper 6 inches was examined by digging a small pit. Lower horizons were examined using a plug soil sampler.

Field work schedules. Field data were collected in the fall of 1957 and spring and summer of 1958. Supplementary work in the field was done early in the spring of 1960.

The field work was conducted in several stages. In 1957 when the work was begun, each tree was designated as a subject tree, then measured, bored, and the soil of the site examined. This took a great deal of time, and it was decided early in the fall of 1957 to go over the entire area and simply designate trees for later detailed sampling. While part of the reason for this was to allow a more comprehensive sampling of the Plantation, the dominant consideration was to allow all samples to be chosen before leaf fall, so that there would be no confusion of species (as between southern red and black oak, or southern red and cherrybark oak) which would

be possible when leaves were no longer on the trees.

Under this procedure it was found that a part of the Plantation had been sampled too intensively, and about forty trees originally designated were excluded from later phases of the work. After being designated, trees were examined again and height and other tree qualities recorded.

Thus the designating of the sample trees; the examining of the trees and associated soils, and the boring of trees for age determination often took place at different times. Moreover, supplemental borings at greater heights were later made on the trees that were climbed first.

Plot Examination

Data taken at each tree included four groups of factors: those pertaining to the tree itself, those which were properties of the stand, those which were properties of the soil, and those which were the physical features of the site. They were recorded on the form shown in Figure 2.

Listed here are all the factors ever recorded at any tree in the study. This list, however, developed from a small beginning. The early plots did not include all the variables recorded here. If a variable added later was considered worth testing after the trees were examined the first time, it was recorded on all plots when they were later reexamined. Any variables found unpromising or difficult to obtain without bias were discarded.

The tree. Variables obtained from examination of the tree itself were species, crown class (although in the study only dominants and co-dominants were sampled), present and potential grade of the butt log, merchantable and total height, and d.b.h. (diameter at breast height,

SOIL SITE DATA
(2nd revision)

Date ____________ Tree No. _____

Recorder __________ Species ______

Location ________________________________

Composition: (same topographic unit) Dominants ____________________________

Co-dominants ____________________________

Map unit: BJO, SRO, BO, PO, WO, TP, SG, CBO, C, RB,_______

Topographic position: Ridge, Upper slope, Middle slope, Lower slope, Terrace, Minor bottom, Bottom, other ______________

Apparent surface drainage: Excessive, Good, Fair, Poor Exposure _______

Microrelief: Smooth, Mound & basin, Ridged, other ______________

Slope above tree: ___% ___P.; ___%___P.;___%___P.;___%___P.

below tree: ___% ___P.; ___%___P.;___%___P.;___%___P.

Distance to main drainage channel ______________________

Area draining to tree: Crown width___p., Slope length___p. Angle bounding area draining to tree ____-____=____. Area ______________

Prism count___(includes___dead) + subject tree (factor _______)

Crown class ____________________________

Tree grade: Present ___, Potential ___. Length graded ______________

Heights: Total ___, Merchantable ___, Main branching ___. Stem fork______

Soil series ______________________________________

Soil profile

Depth	Color	Mott	Text	Conc	Struc	Cons

Tree (Date)

Ht.	Diam	Bark thkns	Ring count	Age

Fig. 2. Data sheet used in recording observations.

$4\frac{1}{2}$ feet above the ground). In addition, age was determined from increment cores later in the laboratory. Ranges of diameters and heights for the species studied are given in Table II.

TABLE II. Ranges of diameters and heights of the trees sampled.

Species	D.B.H.	Total height
	(range in inches)	(range in feet)
Southern red oak	10.6-29.6	55-107
White oak	9.1-29.9	59- 97
Tulip poplar	7.3-30.3	56-113
Sweet gum	8.9-22.7	60-114
Cherrybark oak	12.7-23.2	56-112

Grade of the butt log. The butt log of every tree used in the study was graded by the rules devised by the Forest Products Laboratory (1953). The grading was based on certain standards of diameter, length, and proportion of the log in clear-cuttings. Trees too young and hence too small to be included in the grades, were graded as to their probable future grade, assuming the tree developed no new defects.

Increment Cores

Most of the trees did not have the straight, excurrent stem common to conifers that is desirable for height growth measurements. In the trees studied, however, a main stem could be delineated in the otherwise deliquescent crown.

Cores were obtained using an increment borer and a light-weight sectional ladder. It was found that lubricating the bit of the borer

with soap was helpful. Until this practice was adopted the bits were frequently broken when boring oaks.

It was found that cores from the relatively modest heights up to 30 and 40 feet would not suffice for the determination of points for the height growth curves. The procedure then used was to take borings at fourths of the stem height (one-quarter, one-half, and three-quarters full height) and at $4\frac{1}{2}$ feet (d.b.h.).

A core passing through the pith at the tree center was desired. In large trees this was difficult to obtain. If the core missed the center, a second core parallel to it at the proper distance to one side usually hit the center. This is a technique that Reineke (1941) also found effective.

Cores were examined using a nine-power dissecting microscope and slicing a thin shaving off the outside with a sharp blade. Unless this cut was made the rough outside of the core made it difficult to count the rings in the oaks and virtually impossible to count the rings in sweet gum where differences in successive rings are not pronounced.

The best blade for the purpose was found to be a single-edge razor blade sharpened on a fine novaculite oilstone. Double-edge blades were too flexible. Any blade as purchased had to be sharpened so that the edge was not too thin, or it would soon crumble and scratch the cores. The single-edge blade could be held more easily when one corner of the blade was broken off.

A perfectly clean cut with no scratches was found best. While this type of surface was not so necessary with the oaks, it was absolutely necessary with the gum and nearly so with the yellow poplar. Sweet gum rings

were most apparent when the line of sight and the direction of light were nearly in line with the axis of the pores of the wood, and the surface of the cut was perpendicular to them. Staining was not necessary even in sweet gum if the cores were cut properly.

Cores were counted from the pith outward, marking every fifth and tenth ring. If the tree center was not present in the core the distance and rings missing were estimated. This was accomplished using a diagram, a junction of two lines at a 90-degree angle, to represent the center of the tree and two radii at right angles to one another. The core was laid upon this and positioned so that the direction of the rings and the rays centered on the line junction as a substitute for the center of the tree. When the core was judged to be in the proper position, the missing rings could be estimated using the width of the inside rings on the core to give an indication of probable growth. Applequist (1958) has reported on a scribed plastic strip utilizing this principle. He is careful to point out, however, that there is no reason to expect that missing rings would necessarily be of the same width as adjacent rings present in the core.

When the rings had been counted a curve was constructed of height over age. Two years was assumed as age at d.b.h. This added to ring count at that height equalled total age of the tree. Total age less ring count at each height bored yielded an age figure that was used together with the height in constructing height curves.

In any section, counting rings and subtracting them from total age did not give age at the height of the core but the year of growth of the last section; in the same way that a child five years old is actually in

its sixth year, somewhere between his fifth and sixth birthdays.

To give an example, a tree was bored at 34 feet and 23 rings were counted on the core. Assuming that the tree was actually 67 years old (which would not be known unless rings at the base were counted), then the point of boring was somewhere between the tip at the end of 44 years (67-23) and 45 years; it was somewhere in the growth of the 45th year. From the slope of the curve between successive borings the average height growth per year could be determined. It changed gradually throughout the curve --here it was about 1.5 feet.

It was possible for the growing tip at the end of the forty-fourth year, then, to be anywhere in the 1.5 feet below the boring height. The culmination of the growth of the forty-fifth year was somewhere above. Thus the true curve was between the line given by counting rings and subtracting from total age and a line below it which roughly paralleled it. If the growing season was in progress when the measurements were made then the top of the tree (measured by Abney level or clinometer) also needed adjustment, but it would be upward, and smaller in amount if the tree had passed maximum growth.

Determining the Index of Growth

A height growth curve was constructed for each tree from the data obtained from examination of the increment cores. What was desired was a smooth curve that passed the fifty-year point.

It was assumed that d.b.h. lay in the third year of the tree's life (2 years +). Investigations by Day et al. (1960) in red pine make this seem doubtful, since they found much variation. They also found, however,

that growth below d.b.h. was not correlated with that above d.b.h. Because of this and the desirability of a standard age so comparisons could be made, two years to d.b.h. was adopted and used in all height curves. What this actually amounted to was simply figuring individual tree height at 50 years and assuming a like age at d.b.h. for all trees.

It should be noted that the goal in this process was height as a dependent variable, and that the graph is constructed as though height at a certain age was being determined when in reality it was not this but the reverse, age at a certain height, that was being determined. Spurr (1952) has discussed this point, and concluded that the procedure was only "theoretically unsound." Sectioning the stem to find the exact height would be impractical and unnecessary, because age and height are so highly correlated that the two regressions possible (height on age and age on height) would be "almost identical."

Figure 3 shows representative curves for each of the species. The final objective desired from each of the curves was data on height growth of the tree. The height at fifty years was not primary data except when the core coincided with the height at fifty years.

Fifty years was adopted as the standard age, because it is commonly used in other species in the South and so permits comparisons, but other ages may be better for some species. Thirty-five years, for example, may be best for a fast growing species such as tulip poplar. In natural stands some trees such as white oak would be better depicted by a later age, but this will not fit in with relatively short term management. It may not be desirable to wait for white oak to reach maturity if it takes 150 years.

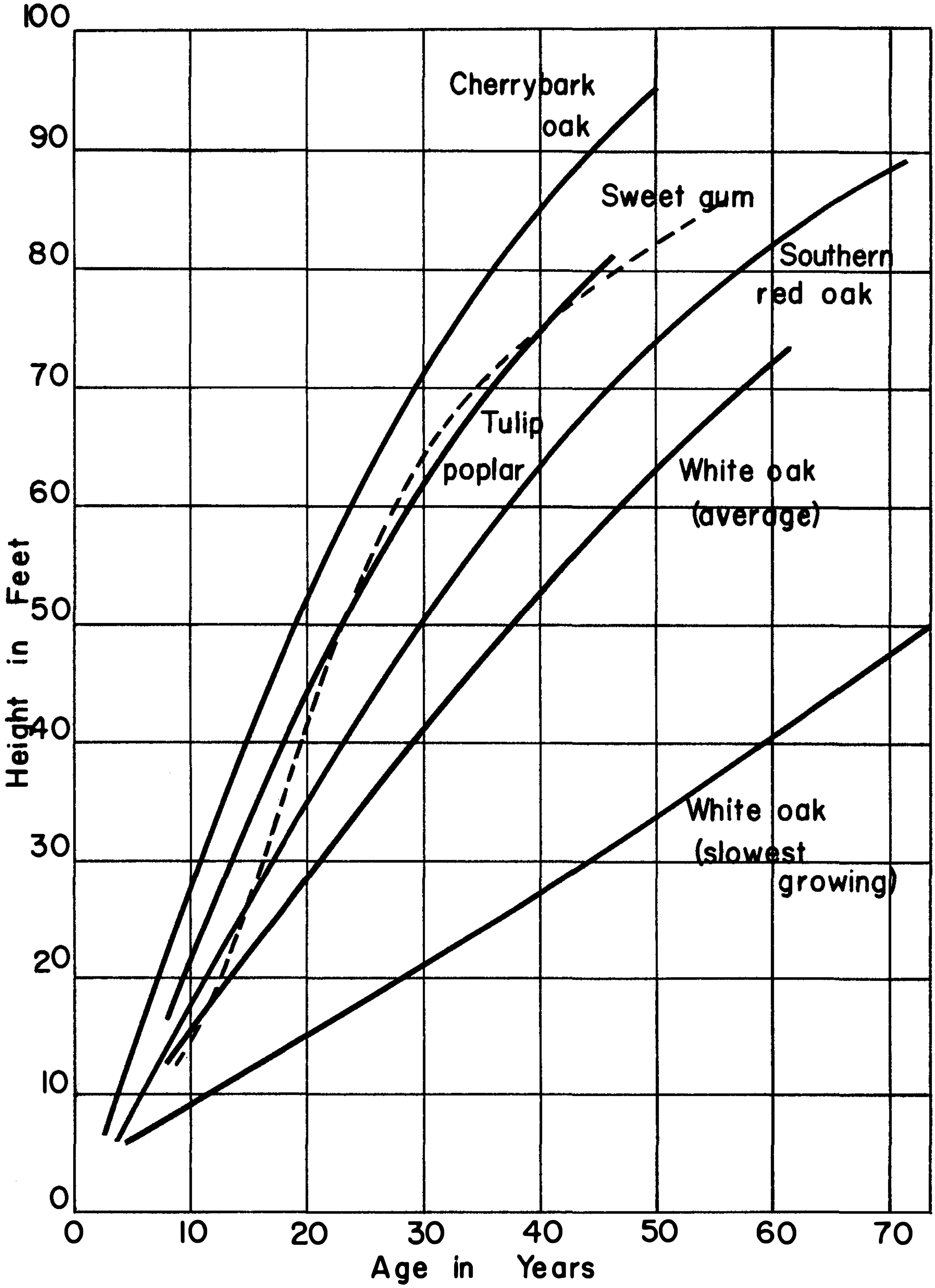

Fig. 3. Cumulative height growth curves of sample trees nearest the average site index for each species.

That more than one kind of curve is possible in a species is apparent from that portion of Figure 3 showing the two types of height growth curves for white oak.

Most curves were satisfactory, but a few were not. Some anomalous curves were highly angular and were discarded and the tree which they represented rejected. It was obvious that some mistake in height measurement or counting had been made.

Interpretation of such effects as broken stems or loss of the terminal bud did not appear to be difficult. These occurrences caused a temporary hiatus in height growth with or without (it was assumed) effects on the subsequent growth rate. If subsequent growth rate was affected, such a tree would be worthless for site index work. However, it was considered doubtful that it would be affected unless breakage was exceptionally severe, and in that case the tree wouldn't have been chosen anyway.

Some curves were not irregular but appeared to indicate suppression. Since this was especially undesirable--suppressed height growth would preclude a reliable index of productivity--such curves were also discarded.

Criteria of suppression were difficult to establish. Extreme depression in the early part of any of the curves followed abruptly by rapid growth was regarded as a sign of suppression and the curve was rejected. More moderate depressions were more difficult to assess. White oak, particularly, displayed some pronounced depressions in the early part of the curves for a number of trees, but this seemed so common that it was suspected that it might be a species characteristic. Perhaps rejection of such trees was too severe a course. There were many white oaks, however, which

displayed no such tendency. Whether these were normal and the others suppressed is not certain; at any rate, any slightly suspicious curves were rejected.

Curves of trees less than 50 years in age had to be extrapolated to reach the index age. Within limits this was considered permissable, since height growth is regular within one tree. If it was considered that the extrapolated curve could by misinterpretation change the height index by 5 feet the tree was rejected.

Assessing Stand Factors

Stand data taken were basal area and species composition.

Basal area. Basal area was determined by the variable plot radius method using a prism (Grosenbaugh 1952 and Bruce 1955). The count was made from the position of the tree, so that it served as the virtual center of the plot. The recorder stood to one side of the tree and examined the trees of the surrounding stand through the prism. The actual position of the prism was offset from the plot center because of the presence of the tree, but it was kept opposite the center of the study tree so that the trees checked through the prism were at the proper distance.

In the prism count all trees registering in the prism sight were counted, down to the smallest size. Dead trees and stumps were counted but a notation was made of their condition. Trees with multiple trunks were counted as one tree if their crowns approximated one tree in the aggregate.

Species composition. To explore the possible relation of stand composition to site productivity a listing of the species present on the site

with each subject tree was made. Presence was noted only in the same topographic unit on which the study tree occurred.

Special notice was taken of species thought especially characteristic of certain sites. Arranged in order, from the one extreme of dry upland sites to the other extreme of lowland sites subject to flooding, they were blackjack oak, southern red oak, black oak, post oak (Quercus stellata Wang.), white oak, tulip poplar, sweet gum, cherrybark oak, cottonwood (Populus deltoides Marsh.), and river birch (Betula nigra L.).

These species and a few others were placed in a dichotomous key by Goodlett (1957) in a preliminary analysis of the vegetation of the Ames Plantation. It was Goodlett's intent to use the key in a primary classification of sites of the Plantation into smaller units. There were fifteen of these units in his key. Each of the species was considered particularly characteristic of a certain site, or of a certain position in the scale of sites from good to poor. The present list reduces the complexity of his scheme somewhat but it may not be as sensitive a device.

This phase of the present study was created to test the possible association of the presence of certain species with the productivity of the sites. If the relations proved consistent and sensitive, then the presence or absence of certain species could be used to predict productivity. With a whole array of species an entire range of sites could be so rated. This method is theoretically more sound than one using simple plant indicators because it is based on the presence of a series of species rather than just one or two.

Physical Features of the Site

Another category of characteristics recorded at each tree site consisted of all those features which might be called the gross physical properties of the site.

Topographic position. Topographic position was evaluated at each site and placed in one of five classes: ridge, upper slope, middle slope, lower slope, terrace or minor bottom, and bottom.

There were some special features of this classification in this region. Listed as ridges were the edges of smooth uplands which were being eroded. The terrace or minor bottom was the flat land in smaller drainways that extended out from the bottom of the slope. It was bounded on one side by the slope and on the other by an escarpment.

Apparent surface drainage. This factor was a subjective evaluation of slope. It was an estimation of the relative drainage class of the site, from "excessive" through "good" and "fair" to "poor".

Exposure. Direction of the slope was determined in degrees azimuth from north.

Microrelief. Under this heading was recorded an evaluation of the surface configuration of the land of the site: whether it was flat, uneven, or rough; or had some special minor characteristic.

Slope. Percent slope was recorded using a Suunto clinometer.

Distance to the drainage channel. Distance to the main drainage

channel below the tree was recorded. This was principally an estimate of the distance to a change in drainage.

Length of slope. The length of slope above the tree was recorded as a measure of the relative size of the drainage area affording runoff (overland flow and seepage) to the tree.

Soil Examination

Soil variables recorded from examination of soil cores were color, mottling, texture, concretions, structure, and consistence. Changes in these qualities through the profile were recorded by depth in inches down to five or six feet. If Coastal Plain materials were not encountered, profiles were examined to greater depths using an 8-foot King tube. Except for a limited number of trees examined at the beginning of the study, color was recorded (in soil examination) using Munsell color charts. Verbal descriptions of soil color were also recorded so that the early examinations could be checked against those made using the charts.

Texture was determined by feel. Soil cores were taken with a soil auger using a tube bit, so that careful separation would show the structure.

Soil series was recorded from the map made by Overton and his party. It was also deduced from profile data.

Tree Factors

Tree measurements entered on the form were: the length graded, crown width, total and merchantable height, and height to main branching.

B. ANALYSIS OF THE DATA

The general scheme of analysis of the data was to produce for each tree site a height over age index which could be tested for correlation with the most promising and logically defensible site factors. The most efficient way of doing this was to enter the recorded values in a multiple regression program.

Processing the Data

When the study was at an advanced stage it developed that it would be possible to process the data by machine. The method used was the regression program devised by Grosenbaugh and Hadek (Grosenbaugh 1958) for the IBM Electronic Data Processing Machine 704. The machine used was owned by the Tennessee Valley Authority and operated at their Computing Center in Chattanooga.

The program uses one dependent variable and correlates it with every possible combination of as many as nine independent variables. While such computation would present a nearly impossible task using a desk calculator, it was accomplished by the IBM machine in a little over an hour.

Since the program accepts no more than nine independent variables the number on our data sheets had to be reduced by eliminating the less promising ones. In some cases the decision was simple. Tree grade and merchantable height could be eliminated from the regression analysis since they were dependent variables, not environmental factors. Their correlation with site index could be tested in another set of computations. Crown class presented only two classes at most and no real array of ordered data, so it

was discarded.

Some other factors could be eliminated because of lack of promise. Microrelief, for example, showed no ordered variation of any consistency that could be correlated with other observations, and slope, though undoubtedly an important variable, was so erratic and complex at individual trees that it was thought that other related factors (slope length, drainage, and topographic position) would come closer to expressing its essence.

There were a number of soil variables, and only the most promising of these were used. The ones considered desirable to test were those affecting the growth of the tree. Thus soil variables that affected the water supply to the roots and the aeration of the roots, and which could be expected to affect the growth processes of roots (respiration and cell differentiation and elongation) and the growth of the stem were considered most important. The variables best presenting all these were considered to be (1) depth to mottling, (2) sand or silt and clay in the 10-30 inch layer, and (3) porosity of the surface layer. No facilities were available for collecting or analyzing for plant nutrients in the soil.

Independent variables. The complete array of independent variables used, then, was as follows (numbers following the terms of classification are the codes used in computation):

X_1 - Topographic position.

Ridge 1
Upper slope . . . 2
Middle slope . . 3
Lower slope . . . 4
Terrace 5
Bottom 6

X_2 - Direction of exposure.

South	1
Southwest	2
Southeast	3
West	4
(no slope) . . .	5
East	6
Northwest	7
Northeast	8
North	9

X_3 - Apparent surface drainage (code comparable to the soil scientist's drainage classes).

Excessive	4
Good	3
Fair	2
Poor	1

X_4 - Slope length above tree (coded as actual length in paces).

X_5 - Basal area (coded as the basal area computed from the tree count plus one for the subject tree multiplied by the prism factor--9.1 in all cases).

X_6 - Competition index. This was a computed figure considered an estimate of the competition afforded the tree. It was found from comparison with independent estimates made at a number of the sites that the number of trees in the prism count of a size equal to half the diameter of the subject tree or above was a satisfactory objective estimate of the number of trees regarded as competitors.

X_7 - Soil depth to mottling in inches (coded as depth in inches).

X_8 - Nominal aeration porosity (volume of the large pores) of the 0-10 inch layer. This was coded as a percentage figure determined by computation from the number of inches of each textural class group recorded on the field sheet for the 0-10 inch layer and weighted according to a volume porosity value for each texture derived from averages for surface soils and subsoils given by Broadfoot and Burke (1951). Pore volumes in percent by textural class group were as follows:

Textural class group	Textural class	Pore volume
Coarse	Sand Loamy sand	24 percent

Textural class group	Textural class	Pore volume
Moderately coarse	Sandy loam	16 percent
Medium	Loam Silt loam Silt	14 percent
Moderately fine	Clay loam Sandy clay loam Silty clay loam	10 percent
Fine	Sandy clay Silty clay Clay	9 percent

X_9 - Nominal percent silt in the 10-30 inch layer of soil. This value was likewise a computed figure using an average percent silt for each textural class (determined from the averages of all the soils presented by Broadfoot and Burke) and weighting these according to the amount of the class present. Percentages of silt by textural class were as follows:

Textural class	Silt content
Silt	87 percent
Silt loam	68 percent
Silty clay loam	58 percent
Silty clay	48 percent
Loam	44 percent
Clay loam	33 percent
Clay	31 percent
Sandy loam	27 percent
Sandy clay loam	22 percent
Loamy sand	11 percent
Sand	7 percent
Sandy clay	6 percent

CHAPTER V

RESULTS

Regressions of Tree Site Index on Site Variables

The IBM 704 regression program yielded the mean and sum of squares of deviations from the mean for each variable. The machine also computed formulas for all possible combinations of up to nine variables. This gave one nine-variable equation, nine eight-variable equations, and so on through seven-, six-, and the rest to nine one-variable regressions. In all, 511 regressions were computed for each species. For each regression the regression sum of squares and the coefficients for the equation itself were furnished.

The amount of association of variation of growth with that of the site variables ranged from as much as 69 to as little as less than 1 percent. Table III shows R^2, in effect the amount of variation in growth explained

TABLE III. Coefficients of determination (R^2) for the nine-variable equation of each species.

Species	Observations	R^2	Adjusted R^2
Southern red oak	64	0.204	0.071
White oak	53	0.175	0.002
Tulip poplar	31	0.676	0.538
Sweet gum	70	0.608	0.549
Cherrybark oak[1]	21	0.707	0.581

[1] Six variables only.

by the most complex of the 511 regression equations (the nine-variable

equation) for each of the species. All of the species showed some relation of growth to the factors of the environment considered, but the amounts varied with the species.

The adjustment of R^2 is that offered by Ezekiel and Fox (1959) and Snedecor (1946) to compensate for samples of small size. Though this adjustment was perhaps not needed for the upland oaks or sweet gum, it was considered desirable for tulip poplar, and more particularly, for cherrybark oak, since the number of observations was very limited in these species. Actually, the adjustment is necessary only when considering R^2 as a percentage of explained variation. The test of significance of R may be made on the unadjusted value.

In southern red oak R^2 is very low, showing that only a small amount of variation in growth is explained by the equations which associate it with the site variables. In white oak the coefficient of determination is even lower. It indicates that about 18 percent of the variation is explained. The adjusted R^2, however, gives a far lower estimate--less than 1 percent.

The three other species--tulip poplar, sweet gum, and cherrybark oak--have much higher coefficients of determination; all above 60 percent.

The low values for southern red oak and white oak are difficult to explain. It may be that the variables used were in inefficient form, or the best variable may not even have been included. An examination of scatter diagrams for the association of tree site index and topographic position, an important variable in all five species relations, did not appear to indicate sufficient curvilinearity to require transformation.

The first suspicion might be directed toward extreme variability of the material. That this was not extreme, however, is apparent from an inspection of the statistics of the height at fifty years of the different species (Table IV).

TABLE IV. Differences in height at fifty years within species samples.

Species	Range	Standard deviation
	(feet)	(feet)
Southern red oak	48 - 97	9.70
White oak	34 - 89	13.74
Tulip poplar	59 - 102	11.43
Sweet gum	57 - 109	11.74
Cherrybark oak	64 - 114	12.06

Surprisingly, differences in the standard deviations were not great. Great variations, then, did not appear to be the cause of the small amount of explained variation in the southern red oak regressions. Nor, apparently, was lesser variation a possible explanation of the high R^2 in cherrybark oak.

The significance of R for the nine-variable regressions was tested against tabular values determined by Snedecor (Guilford 1956, pp. 538-539) with the results given in Table V.

TABLE V. Coefficients of multiple correlation (R) for the nine-variable equation of each species.

Species	R
Southern red oak	0.451 ns[1]
White oak	0.418 ns
Tulip poplar	0.822 **[2]
Sweet gum	0.780 **
Cherrybark oak	0.841 **[3]

[1] not significant

[2] significant at the 1-percent level

[3] six-variable equation

Southern red oak. The regressions for southern red oak showed poor association of site index with the environmental factors. With all nine variables present the coefficient of determination, R^2, was 0.204, which was adjusted to 0.071 in recognition of the size of the sample, so the portion of growth associated with variations in the nine variables all together was very low--7 percent as a conservative estimate.

Dropping off successively the variables contributing the least to the regression sum of squares (Table VI) led to discarding X_9, nominal percent silt in the 10 to 30 inch layer; X_5, basal area of the stand; and X_4, slope length above the tree. The best equation of the 6-variable regressions, which remained at this stage, was significant at the 5-percent level.

TABLE VI. Regressions of tree site index of southern red oak on environmental factors listed in sequence of the highest sums of squares, dropping one variable at a time.

Number of variables	Variables present		Variables separated	R^2
9	$X_1X_2X_3X_4X_5X_6X_7X_8X_9$	ns		0.204
8	1 2 3 4 5 6 7 8	ns	9 ns	0.203
7	1 2 3 4 6 7 8	ns	5 ns	0.202
6	1 2 3 6 7 8	*[1]	4 ns	0.199
5	1 2 3 7 8	*	6 ns	0.194
4	1 2 3 8	*	7 ns	0.186
3	1 2 3	**	8 ns	0.171
2	1 3	**	2 ns	0.159
1	3	**	1 ns	0.128

[1] Significant at the 5-percent level.

The dropping of separate variables was continued with the loss of X_7, depth to mottling; X_8, aeration porosity of the 0-10 inch layer; X_2, direction of slope or exposure; and X_1, topographic position. All these variables when tested were shown to add no significant amount to the reduction in variability occasioned by the use of the regression equation. At this stage the sole remaining variable was X_3, apparent surface drainage (Table VII).

TABLE VII. Analysis of variance of tree site indices of southern red oak.

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Regression, Y on X_3	1	758.311	758.311	9.10**
Residual	62	5167.173	83.342	
Total	63	5925.484		

When the factors were tested as single variables, X_1, topographic position, and X_3, apparent surface drainage, proved to be significant, the former at the 5-percent level and the latter at the 1-percent level. Variable X_1, although it added no significant reduction to the residual sum of squares in the regression of Y on X_3, was significant as a single variable, and X_3 added a significant reduction to this residual sum of squares (Table VIII).

TABLE VIII. Analysis of variance of the regression of tree site index (Y) of southern red oak on topographic position (X_1) and apparent surface drainage (X_3) testing the contribution of X_3 to the regression.

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Regression, Y on X_1X_3	2	939.227	469.614	5.74**
Regression X_1	1	587.143	587.143	
Added reduction due to X_3	1	352.084	352.084	4.31*
Residual	61	4986.257	81.742	
Total	63	5925.484		

For these reasons the best equation for southern red oak was considered to be that including both X_1 and X_3:

$$Y = 80.8386 + 1.38163X_1 - 3.97032X_3$$

This was rounded to,

$$Y = 80.8 + 1.4X_1 - 4.0X_3$$

Standard error of estimate was 9.0. Mean estimated Y was 73.2 The 95-percent confidence interval would extend 18 feet either side of the regression line ($t_{.05}$ = 2.000, d.f. = 61). Clearly the predictive equation

for southern red oak is of little value, but it should be remembered that this is for single trees and the average on a particular site would have a narrower confidence interval.

The height of southern red oak at fifty years was associated to a limited extent with differences in drainage. Locations where drainage was excessive were poor sites, and where drainage was not so great or was even retarded, sites were better. Within drainage classes some difference in growth was associated with topographic position, the lower slope positions being better than positions near or on the ridges.

White oak. Variation was slightly higher in white oak and this in part (but probably only in part) explained the lower coefficient of determination in this species.

Examination of the mean squares of the separate variables showed only X_1, topographic position, to be significant, and that only at the 3.3-percent level. All the other factors tested singly did not show any significance. The highest of these was X_9, percent silt in the 10-30 layer, which had an F value showing a probability of 0.185, or about one chance in five of occurring fortuitously.

Analysis in sequence, following the largest regression sums of squares, took the pattern of Table IX in white oak. Apparently the best equation for predicting white oak growth was a simple regression of height growth on topographic position, but it explained only a very small part of the variation (unadjusted r^2 was 0.086). The equation expressing this relation was

$$Y = 52.2 + 3.0X_1$$

TABLE IX. Regressions of tree site index of white oak on environmental factors listed in sequence of the highest sums of squares, dropping one variable at a time.

Number of variables	Variables present	Variable separated	R^2
9	$X_1X_2X_3X_4X_5X_6X_7X_8X_9$ ns		0.175
8	1 2 3 4 6 7 8 9 ns	5 ns	0.175
7	1 2 3 4 7 8 9 ns	6 ns	0.175
6	1 2 4 7 8 9 ns	3 ns	0.173
5	1 2 7 8 9 ns	4 ns	0.167
4	1 2 7 9 ns	8 ns	0.162
3	1 7 9 *	2 ns	0.155
2	1 9 *	7 ns	0.122
1	1 *	9 ns	0.086

Calculated mean Y was 61.6 and the standard error of estimate was 13.3. The 95-percent confidence interval would be a band extending 27 feet above and below the regression line at the mean. The great extent of the variation is evident from the dispersion of the individual points as shown in Figure 4.

The predictive equation for white oak was thus of even less value than that for southern red oak, but again it should be recognized that the equation predicts for single trees, and the average on any one relatively homogeneous site would be more precise.

Southern red oak and white oak were, of the five species studied, the ones showing the least association between independent variables and growth. The three remaining species studied, tulip poplar, sweet gum, and cherrybark oak, showed a high degree of association of the growth variable with independent variables of site. The R^2 for tulip poplar was 0.676; for sweet gum, 0.608; and for cherrybark oak, 0.707 for the 9-variable regressions.

Tulip poplar. Tested individually in simple regressions, only three of the nine independent variables used in the regressions proved significantly related to individual tree site index of tulip poplar. Topographic position (X_1) was highly significant, and apparent surface drainage (X_3) and nominal aeration porosity of the surface soil (X_8) were significant.

Tulip poplar regressions were highly significant at the 9-variable stage. Dropping in each case the least effective variable (Table X) successively eliminated X_9, nominal percent silt in the 10-30 inch layer;

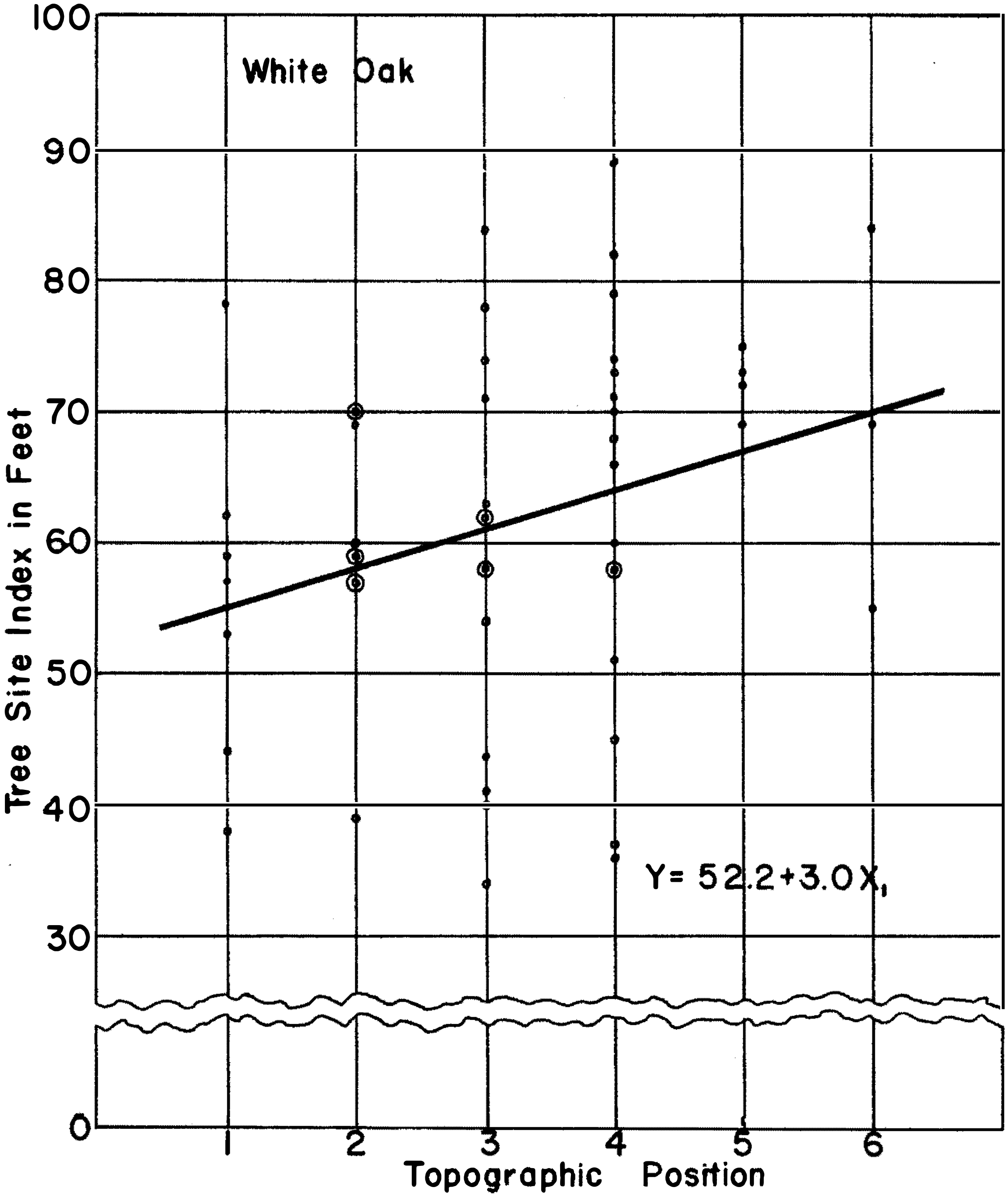

Fig. 4. Regression of tree site index of white oak on topographic position and scatter diagram of the site indices of the sample trees.

X_3, apparent surface drainage; X_4, slope length above the tree; X_5, basal area; X_6, competition index; and X_8, nominal aeration porosity. None of these contributed a significant addition to the regression sum of squares.

TABLE X. Regressions of tree site index of tulip poplar on environmental factors listed in sequence of the highest sums of squares, dropping one variable at a time.

Number of variables	Variables present		Variable separated	R^2
9	$X_1X_2X_3X_4X_5X_6X_7X_8X_9$	**		0.676
8	1 2 3 4 5 6 7 8	**	9 ns	0.675
7	1 2 4 5 6 7 8	**	3 ns	0.670
6	1 2 5 6 7 8	**	4 ns	0.662
5	1 2 6 7 8	**	5 ns	0.625
4	1 2 7 8	**	6 ns	0.612
3	1 2 7	**	8 ns	0.565
2	1 7	**	2 *	0.459
1	1	**	7 **	0.275

The three variables remaining at that point each contributed a significant addition to the regression sum of squares. They were X_2, direction of exposure, significant at the 5-percent level; X_7, depth to mottling, significant at the 1-percent level; and X_1, topographic position, significant at the 1-percent level (Table XI). Depth to mottling had a low value by itself, but in the presence of slope direction or topographic position, it had a great effect. Apparent surface drainage and nominal aeration porosity, variables that had significant mean square ratios in simple regressions,

showed no great effect when grouped with others. This was probably because drainage, porosity, and mottling are related factors.

TABLE XI. Analysis of variance of tree site indices of tulip poplar testing the contribution of variables other than X_1, X_2, and X_7.

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Regr., 9 var.	9	2651.55	294.62	4.88**
Regr. $X_1X_2X_7$	3	2215.96	738.65	
Added reduction due to other variables	6	435.59	72.60	1.20ns
Residual	21	1268.39	60.40	
Total	30	3919.94		

The predictive equation for tulip poplar was

$$Y = 41.2 + 5.3X_1 + 2.3X_2 + 0.2X_7.$$

The standard error of estimate was 7.9, indicating a 95 percent confidence interval 16 feet above and below the regression line at the mean (84.3).

Sweet gum. Simple regressions of height growth at fifty years of sweet gum on separate independent variables showed very high significance for topographic position and apparent surface drainage, high significance for depth to mottling, and significance at the 5-percent level for slope length above the tree. The variance ratio of each simple regression is shown in Table XII.

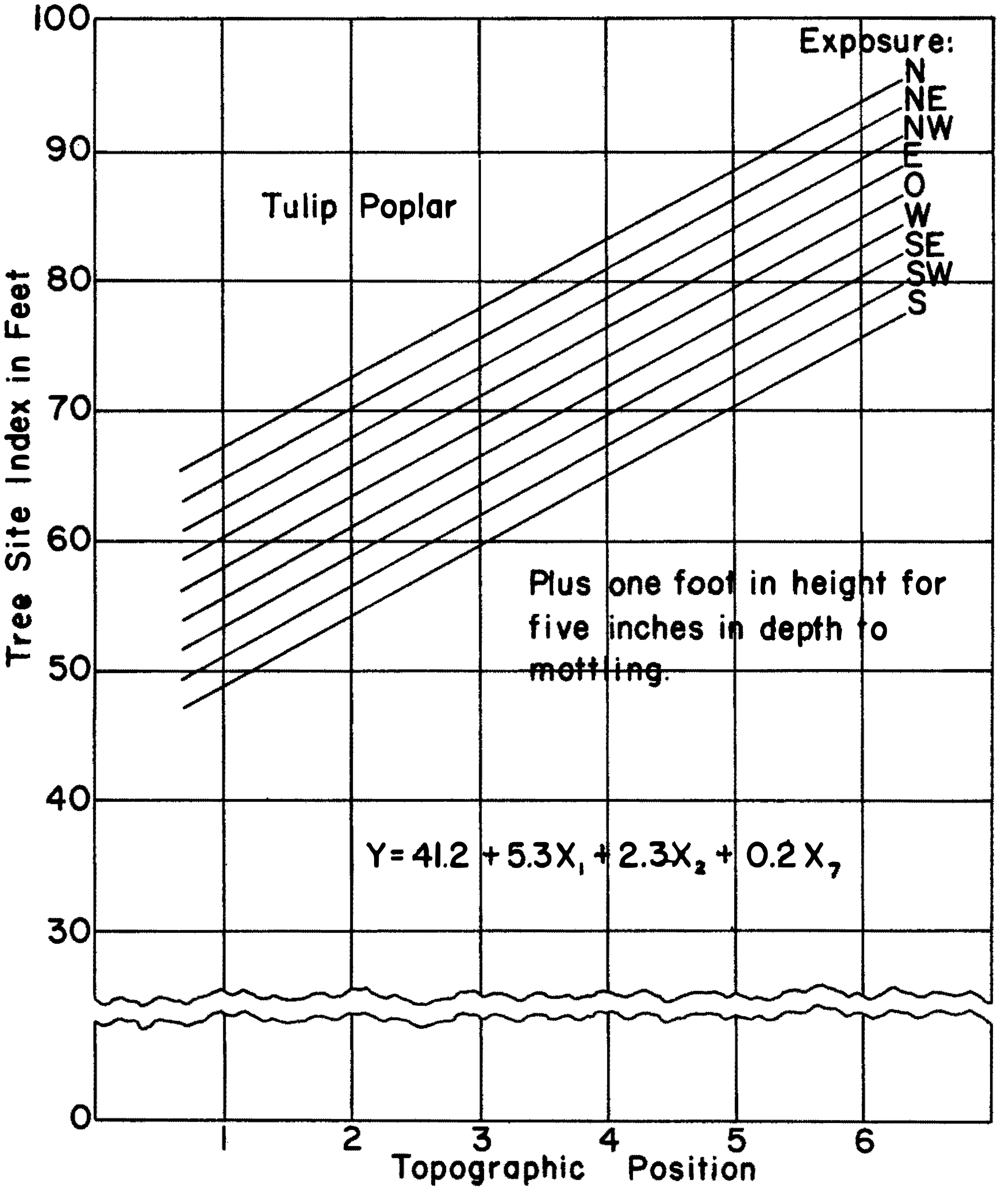

Fig. 5. Regression of tree site index of tulip poplar on topographic position, direction of exposure, and depth to mottling.

Despite five variables proving significant in simple regressions, most of the variables could have been dropped from the 9-variable regression without losing added reduction of significance.

TABLE XII. Effectiveness of the independent variables in simple regressions of the tree site index of sweet gum.

Variable	F
X_1 Topographic position	74.61 **
X_2 Direction of slope	0.74
X_3 Apparent surface drainage	39.89 **
X_4 Slope length above tree	3.98 *
X_5 Basal area	2.82
X_6 Competition index	4.16 *
X_7 Depth to mottling	13.84 **
X_8 Porosity of 0-10" layer	2.54
X_9 Silt in 10-30" layer	1.60

The first of the variables dropped, when the path of the largest sums of squares was followed, was X_7, depth to mottling (Table XIII). In simple regression this factor proved to be highly significant, but it added little to the 8-variable regression. After this followed X_4, slope length above the tree (significant in simple regression); X_5, basal area; X_9, silt content of the 10-30 inch layer; and X_2, direction of slope. The remaining variables, X_1 and X_3 (topographic position and apparent surface drainage), were significant in combination and also in simple regressions.

TABLE XIII. Regressions of tree site index of sweet gum on environmental factors listed in sequence of the highest sums of squares, dropping one variable at a time.

Number of variables	Variables present	Variable separated	R^2
9	$X_1X_2X_3X_4X_5X_6X_7X_8X_9$ **		0.608
8	1 2 3 4 5 6 8 9 **	7 ns	0.607
7	1 2 3 5 6 8 9 **	4 ns	0.607
6	1 2 3 5 6 9 **	8 ns	0.607
5	1 2 3 5 9 **	6 ns	0.603
4	1 2 3 9 **	5 ns	0.597
3	1 2 3 **	9 ns	0.588
2	1 3 **	2 ns	0.565
1	1 **	3 *	0.523

All variables but X_1 and X_3 were shown to add a negligible reduction to the regression (Table XIV). The regression of the remaining variables--X_1 and X_3--proved significant, and either variable added to the reduction, though variable X_1, topographic position, was more effective as seen from the F values of tests of the reduction added by variables X_1 and X_3 (Table XV).

The regression equation available for prediction of height growth in sweet gum was

$$Y = 72.3 + 4.3X_1 - 3.4X_3.$$

The standard error of estimate was 7.9, which gave a 95 percent confidence interval of 16 feet above and below the regression line at the

mean (83.1). Thus this predictive equation also is not very precise for individual trees.

TABLE XIV. Analysis of variance of tree site indices of sweet gum testing the contribution of variables other than X_1 and X_3 to regression.

Source of variation	Degrees of freedom	Sum of squares	Mean Square	F
Regression, 9 variables	9	5775.32	641.70	10.33 **
Regr. X_1X_3	2	5368.22	2684.11	
Added due to $X_{2456789}$	7	407.10	58.16	ns
Residual	60	3727.77	62.13	
Total	69	9503.09		

TABLE XV. Analysis of variance of tree site indices of sweet gum, comparing the contribution of variable X_1, topographic position, and X_3, apparent surface drainage, to the predictive equation.

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Regression, X_1X_3	2	5368.22	2684.11	43.50 **
Regr. X_1	1	4971.72	4971.72	
Added reduction due to X_3	1	396.50	396.50	6.42 *
Regr. X_3	1	3513.54	3513.54	
Added reduction due to X_1	1	1854.68	1854.68	30.05 **
Residual	67	4134.87	61.71	
Total	69	9503.09		

The graphical portrayal of this relation is presented in Figure 6.

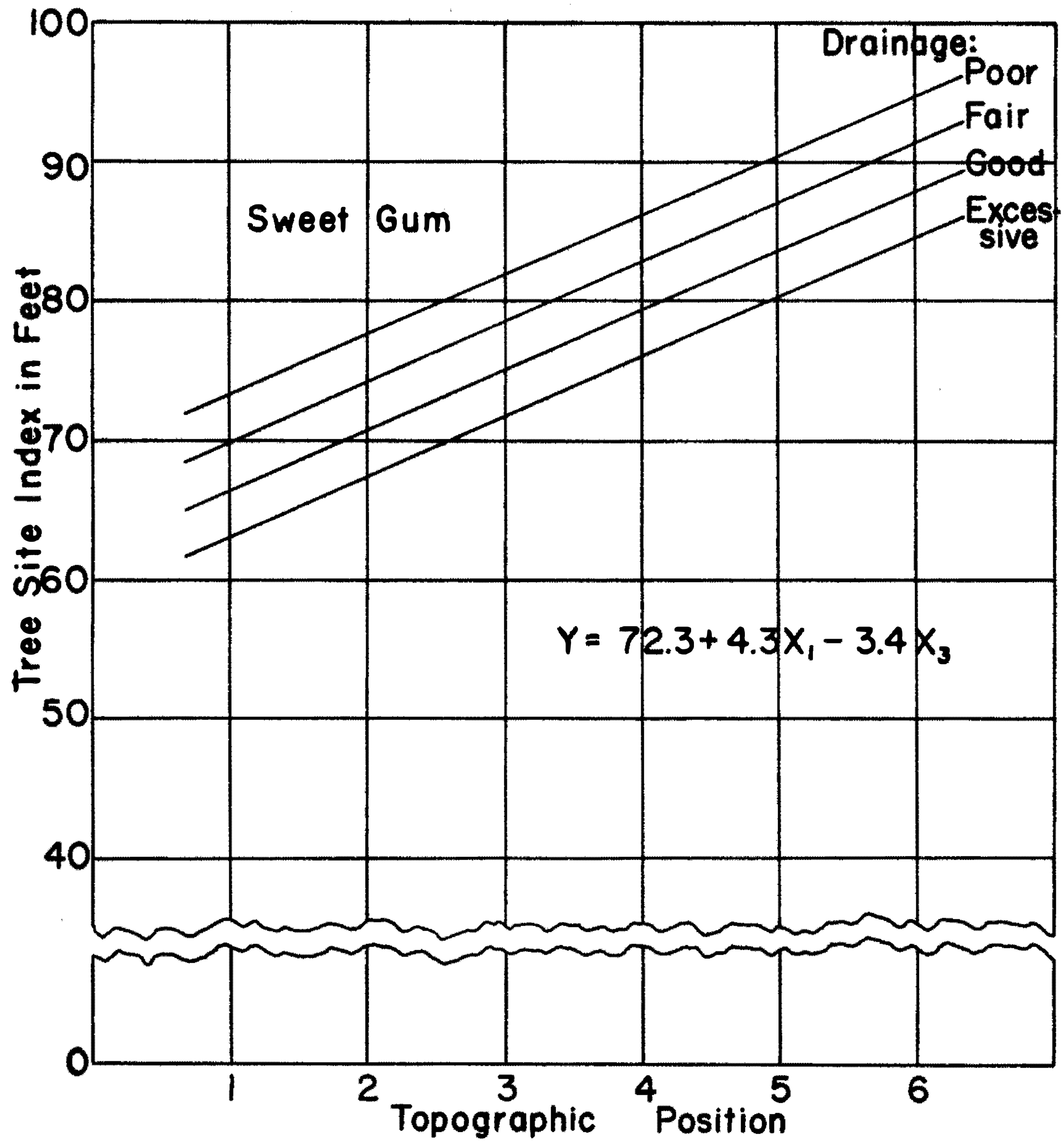

Fig. 6. Regression of tree site index of sweet gum on topographic position and apparent surface drainage.

Height growth in sweet gum apparently was closely related to position on the slope and drainage class, the poorer sites being on the ridges and the better ones in the bottoms. This of course was an aspect of the moisture regime near the tree, the lower sites being more moist. Drainage also affected the moisture regime. Apparently in sweet gum the increased moisture available under poor drainage conditions was advantageous. Note that on the graph a unit change in topographic position and a unit change in drainage have about the same magnitude of effect on height at 50 years.

Cherrybark oak. It was found from scatter diagrams that due to limited sampling three of the variables used in regressions of cherrybark oak were biased and bunched in such a way as to give unwarranted high values of correlation. These variables: X_1, topographic position; X_2, direction of exposure; and X_4, slope length above the tree, were excluded from the series of regressions, with a consequent general lowering of values of R^2.

TABLE XVI. Regressions of tree site index of cherrybark oak on environmental factors listed in sequence of the highest sums of squares, dropping one variable at a time.

Number of variables	Variables present	Variable separated	R^2
6	$X_3X_5X_6X_7X_8X_9$ **		0.707
5	3 5 6 7 9 **	8 ns	0.707
4	3 5 6 7 **	9 ns	0.679
3	3 5 7 **	6 ns	0.661
2	3 5 **	7 ns	0.615
1	3 **	5 *	0.465

Following the sequence of the largest sums of squares and testing the contribution of separated variables (Table XVI) led to the discard of all remaining variables (Table XVII) but X_3, apparent surface drainage, and X_5, basal area.

TABLE XVII. Analysis of variance of tree site index of cherrybark oak testing the significance of variables in regressions.

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Regression, $X_3X_5X_6X_7X_8X_9$	6	2057.43	342.90	5.62 **
Regr. X_3X_5	2	1789.39	894.70	
Added reduction due to X_{6789}	4	268.04	67.01	1.10 ns
Residual	14	853.81	60.99	
Total	20	2911.24		

The equation employing the two significant variables accounted for approximately 46 percent of the variation in tree site index of cherrybark oak. This predictive equation was:

$$Y = 95.7 - 8.1X_3 + 0.1X_5.$$

Mean estimated Y was 95.8 and the standard error of estimate was 7.9. The 95-percent confidence interval would extend about 16 feet above and below the mean. The predictive equation is presented graphically in Figure 7.

Species-Variable Comparisons

By way of summary, Table XVIII shows the five species studied and the nine variables with those that proved significant in simple regressions

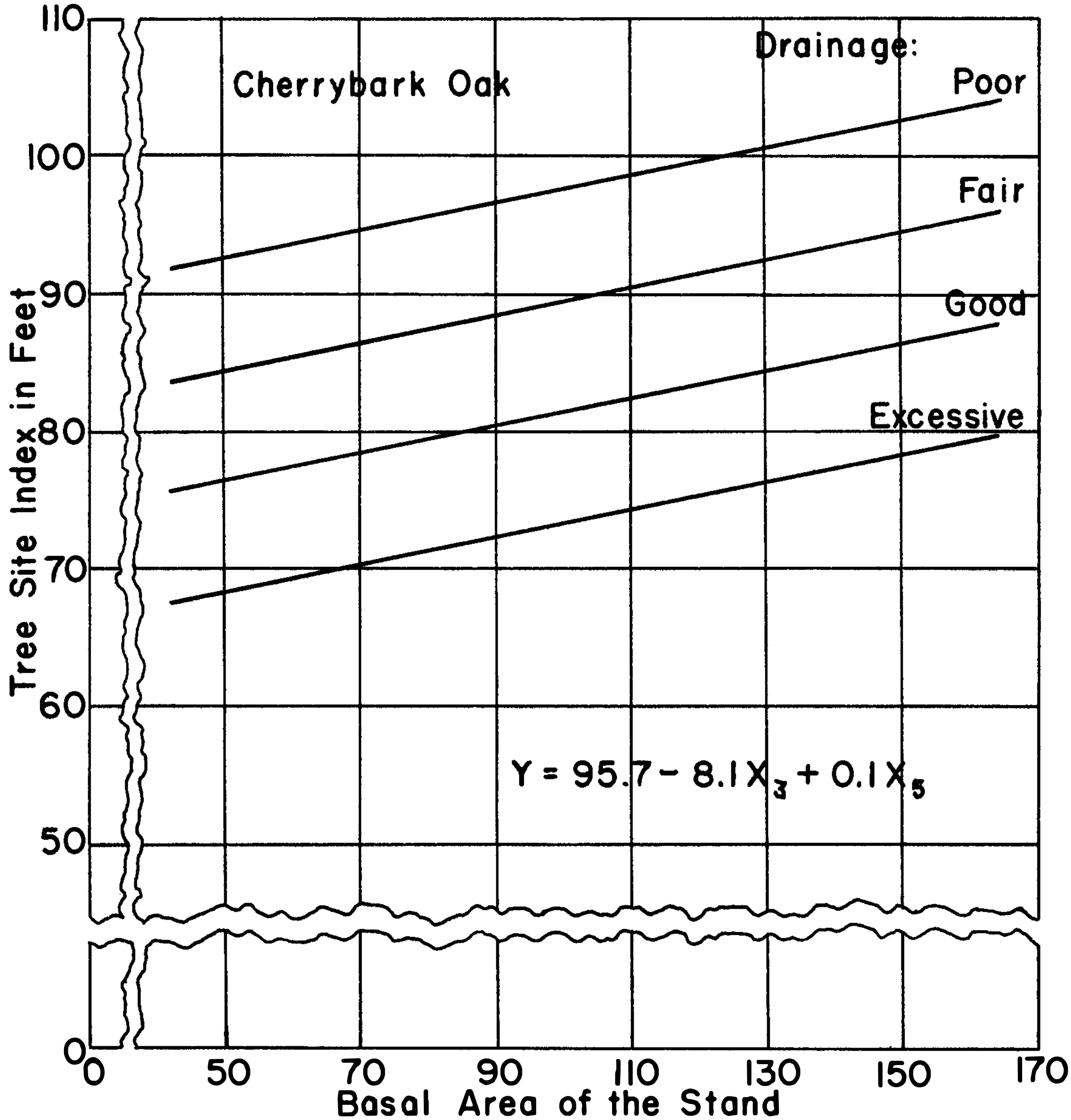

Fig. 7. Regression of tree site index of cherrybark oak on apparent surface drainage and basal area of the stand.

marked for each species. Connected circles show the combinations of variables that proved most effective.

The most consistently effective variable was topographic position, and the next most effective was apparent surface drainage. Both of these are classification variables and are to a certain degree subjective. Stand variables, basal area and competition index, were not prominent, being associated only with site index of cherrybark oak and sweet gum, respectively, and that only in simple regressions. Some variables in combination did not have the effect they did in simple regressions, and others that had no effect as single variables were effective in combinations with others.

Species Composition and Tree Site Index

The data on the species composition at each site showed that there was a certain correlation of site differences with the series of critical species. This relation was weak, however, so the predictive value of species presence or absence on the sites seemed questionable. The relations tested were elusive, and the methods of testing were not rigorous. The relations apparent seemed hardly strong enough to be reduced to a systematic set of rules.

Table XIX shows the species composition and productivity data of sweet gum. This was the best correlation observed in any of the five species studied. Though the relation was not strong there was a definite banding of the data. High productivity rates tended to be associated with the presence of river birch, and low rates with the presence of blackjack oak, black oak, post oak, and white oak. The relation was not nearly as marked in the other species of the study, although there seemed an indication that

TABLE XVIII. Significance of the separate variables in simple regressions, and the most effective combinations of variables in multiple regressions.

Variable	Southern red oak	White oak	Tulip poplar	Sweet gum	Cherrybark oak
X_1 Topographic position	* o	*	** o	** o	(omitted)
X_2 Direction of exposure	|		o	|	(omitted)
X_3 Apparent surface drainage	** o		* |	** o	** o
X_4 Slope length above tree			|	*	(omitted) |
X_5 Basal area			|		* o
X_6 Competition index			|	*	
X_7 Depth to mottling			o	**	
X_8 Aeration porosity of 0-10" layer			*		
X_9 Percent silt in 10-30" layer					

(Combinations were significant at the 1-percent level. Variables excluded from the final cherrybark oak equations were omitted because their distributions were biased in the samples obtained.)

TABLE XIX. Frequency of key species in the surrounding stand relative to the tree site index of sweet gum.

Height at 50 years (feet)	Black-jack oak	South. red oak	Black oak	Post oak	White oak	Tulip Poplar	Sweet gum	Cherry-bark oak	Cotton-wood	River birch
105-109							1	1		1
100-104						2	5			4
95-99						1	6	4		7
90-94		3				3	8	1	1	4
85-89		4		1	1	3	10	3		4
80-84	1	6	3		8	4	13	3		
75-79		3	1	4	4	2	9	1		
70-74		3	1	3	1	2	5			
65-69	2	5	1	1	2		7	1		
60-64		1	2	1	2		3			
55-59		1					1			

on sites bearing tulip poplar or white oak of relatively high tree site index, sweet gum was more frequent.

Some correlation was noted on southern red oak sites--a slight association of high tree index with greater frequency of sweet gum, and of lower tree index with greater frequency of blackjack oak. High tree site index values for sweet gum seemed associated with greater frequency of river birch in adjacent stands. The species observed growing in stands with cherrybark oak showed almost no association with variations in site productivity for that species. On sweet gum sites, southern red oak was present on such a wide variety of sites that it seemed out of place in the array of species. It occurred on much more productive sites than the species usually associated with it, and even on more productive sites than white oak.

Soil Series and Tree Site Index

Table XX lists the soils of the Plantation (following Overton et al., 1951) and in neighboring columns shows by species the number of individual trees studied on each of these soils. Some soils were not sampled at all, and the soils that were sampled were not sampled with like intensity for each species. Prominent in the first of these groups were productive agricultural soils and also a few soils only sparingly represented on the Plantation. What is not apparent from the table is that in addition to the soil and species variations, there were also differences due to location, since sites were sampled in seventeen different sampling areas.

Since the data are incomplete, few orthogonal comparisons of the productivity of these soils in terms of tree site index were possible.

TABLE XX. Soils of the Ames Plantation and the number of sample trees examined on each by species.

Soil series	Southern red oak	White oak	Tulip poplar	Sweet gum	Cherrybark oak	Total
Memphis	9	4	-	7	-	20
Loring	4	10	3	1	1	19
Grenada	-	-	-	-	-	-
Calloway	-	-	-	-	-	-
Henry	-	-	-	-	-	-
Lexington	11	3	1	5	-	20
Ruston	14	8	5	6	-	33
Susquehanna	-	-	-	-	-	-
Gullied Land[1]	12	7	3	3	1	26
Tigrett	5	9	3	6	1	24
Briensburg	-	1	-	4	1	6
Dyer	-	-	-	-	-	-
Gully Wash[1]	6	4	6	10	-	26
Lintonia	-	-	-	1	1	2
Richland	-	-	-	-	-	-
Olivier	-	-	-	-	-	-
Calhoun	-	-	-	-	-	-
Dexter	-	2	1	1	-	4
Freeland	-	-	-	-	-	-
Chattahoochee	-	2	-	-	-	2
Hymon	-	-	-	-	-	-
Ina	-	1	5	14	10	30
Beechy	-	-	2	4	2	8
Tombigbee	-	-	-	-	-	-
Sand Overwash[1]	3	2	2	8	5	20

[1] Not a soil series, but a "miscellaneous land type" used by Overton et al. (1951) in classifying Ames Plantation soils.

When sampling within a compartment had been so intensive that data were available on a number of soils bearing the same species, comparisons of soil effects were possible.

Since the analysis of variance specifies samples displaying normal distribution, and since it was probable that the site productivity values were not normally distributed, they were transformed before computations were made. The tree site indices were converted first to percentages of the highest value for each species (if 110 was the highest tree site index it constituted 100 percent, and an index value of 99 was then 90 percent). The arc sin transformation was used on these values.

Comparison of all species pooled (omitting only cherrybark oak) on Memphis and on Loring soils showed error mean square much larger than that for soils differences. Error mean square in this case was probably largely made up of species differences.

Comparison within one compartment of southern red oak on Memphis, Lexington, and Ruston soils, and Gullied Land, one of the "miscellaneous land types" of the Overton report, showed mean square from soils differences to be much smaller than mean square from random variation, hence the differences were far from significant.

Comparison of sweet gum on Tigrett and on Sand Overwash was also inconclusive, as was a comparison of the same species on Ina and Sand Overwash, two bottomland soils in a single location, the bottom near the old Duscoe house (Table XXI).

Some few orthogonal comparisons were possible between sampling areas, with species and soil series constant. Sweet gum growing on Ina

soil at four sites showed no mean square of any significance.

TABLE XXI. Analysis of variance of angles = arc sin $\sqrt{\%}$ maximum tree site index to test soil series differences as shown in growth of sweet gum.

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Soils (Ina vs. Sand Overwash)	1	92.0326	92.0326	1.19 ns
Error	6	464.6774	77.4462	
Total	7	556.7100		

Nor on upland sites were any great differences found. Southern red oak growing on Ruston soil at four different locations allowed the test in Table XXII. Differences of location and differences in soil series seem to be about of the same magnitude.

TABLE XXII. Analysis of variance of angles = arc sin $\sqrt{\%}$ maximum tree site index of southern red oak testing soils differences by sampling areas.

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Sampling areas	3	217.8615	72.6205	1.45 ns
Error	10	500.0763	50.0076	
Total	13	717.9378		

It was apparent that soil productivity differences were not very closely associated with differences in soil series. There seemed to be a great range in productivity within series.

Figures 8 and 9 depict this range within soil series graphically. Here are shown, for the soils entering into the study observations, ranges of tree site indices for white oak and sweet gum. The soils are arranged in order of topographic position from upland to bottom, and within each of these groupings, in order of decreasing drainage. The white oak and sweet gum charts are presented because they seemed representative. In analysis, charts like these were also drawn for southern red oak, tulip poplar, and cherrybark oak.

The white oak ranges were especially wide, wider than those in any other species, with much overlapping of the ranges for different soils. The wide ranges apparent in the figure show the great variability of this species.

The second figure, that for sweet gum, shows a great amount of overlapping in site indices of that species too. Also apparent is an increase in site index ranges as soils of lower topographic position are considered. Such ordering was not found in any other species.

The conclusion was that there was so much overlapping of ranges of productivity of any one species on different soil series that the series was at best only a very approximate forest productivity indicator.

The species not included in the figures were not essentially different. In southern red oak all Memphis, Loring, Lintonia sites were included within the range of the Ruston sites. All other sites recorded were mostly within this range, but for Gullied Land the poorest site value was below this range, and for Tigrett, Gully Wash, and Sand Overwash, the best site was slightly above it. Tulip poplar sites showed even more similarity,

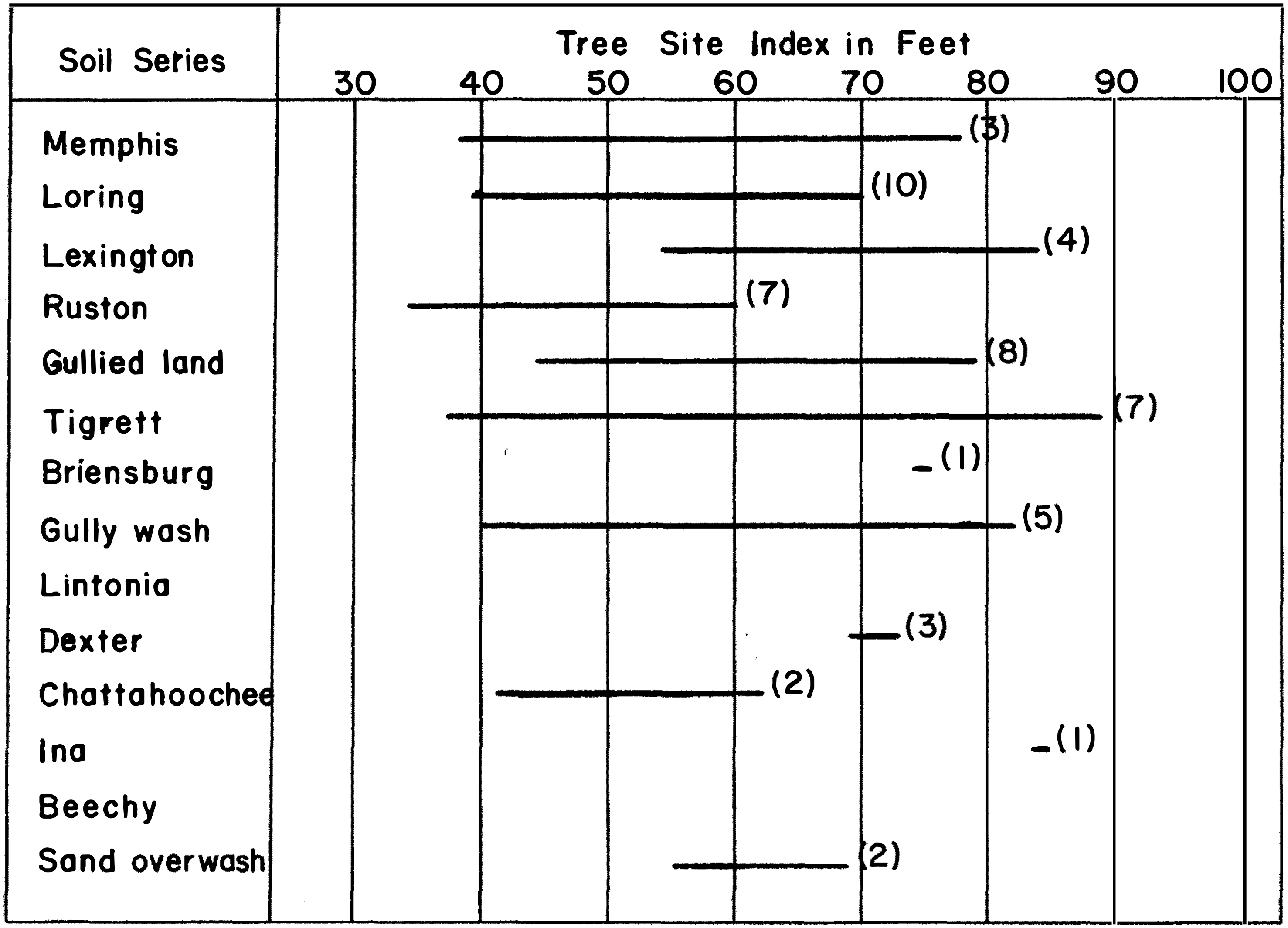

Fig. 8. Ranges of tree site indices of white oak within the soil series studied. Number of sample trees in parentheses.

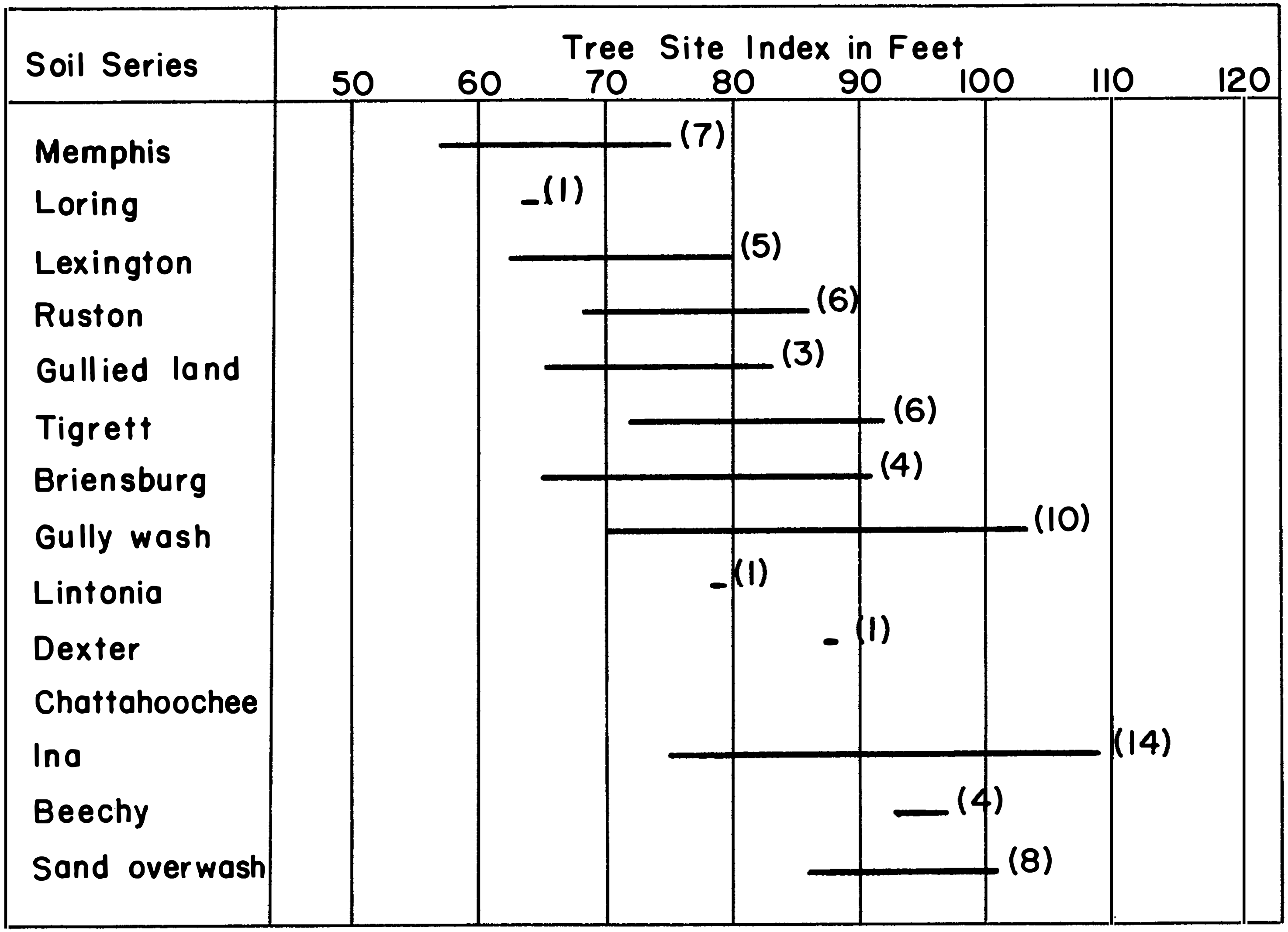

Fig. 9. Ranges of tree site indices of sweet gum within the soil series studied. Number of sample trees in parentheses.

with marked overlapping between site values on different soil series.

Among the very few observations on cherrybark oak, soils of upland sites were low, and bottomland soils were high, but ranges overlapped greatly.

Tree Grade and Site Index

It was expected that tree grade would be highly correlated with the productivity of the site. In order to test this, coefficients of correlation for the association of these two factors were calculated. Since the higher the grade the lower the grade number, correlation of better grades with better sites would have been negative. The values were very low (Table XXIII). Scatter diagrams of tree site index values in relation to

TABLE XXIII. Correlation of tree site index and tree grade, by species.

Species	Correlation coefficient
Southern red oak	-0.022
White oak	0.110
Tulip poplar	0.066
Sweet gum	-0.383
Cherrybark oak	-0.267

grade for each species revealed great variation in index values within each grade.

The highest coefficient of correlation, the one for sweet gum, explained little more than ten percent of the variation in tree grade by

associating it with variation in tree site index. The lack of correlation was surprising because high site quality and high tree quality are commonly thought to be associated. Proceeding on this assumption, Trimble and Weitzman (1956) also had disappointing results when studying upland oaks. They found clear length of bole a poor index of site; standard error of estimate was 27 percent.

A possible cause of the lack of correlation lies in the methods of grading hardwoods. Hardwood grades are much affected by the presence of small defects other than knots, which unlike knots, do not seem to be lacking in large trees. Though high site index would usually mean few limbs, in hardwoods it would not necessarily mean few defects.

CHAPTER VI

CONCLUSIONS

Site Quality Determinations in Uneven-Aged Forests

For uneven-aged stands the determination of site index is difficult. This is especially so if the effective variables vary with the species, as well they may. Most site index work has been done in even-aged stands where stand averages could be obtained. For the measurement of stand dimensions, averages would of course be more reliable than data from separate trees. When correlation of two variables is being explored, however, a series of individual pairs of values is more reliable than averages at several points.

The method used in this study to derive indices of site productivity --the construction of height growth curves for single trees based on height and age measurements--was an attempt to cope with the problem of site index determination in uneven-aged stands. The tree site index was regarded as a biological datum, limited only to the extent that it was for some trees an interpolation of a curve.

Although the study's original purpose was not to test the method used, it did afford an opportunity for evaluating it. From the results with sweet gum, tulip poplar, and cherrybark oak, it was apparent that the method could be used in testing the association of tree site index with site variables, but there was little precision in the data. Although height growth was associated with certain variables, there was great variation around predicted values. This was probably due to using individual tree data. Thus there was much variation from tree to tree that would

not have been apparent had all tree measurements been referred to a set of standard site index curves.

Considering the results more specifically, the low values of the coefficients of determination for southern red oak and white oak were apparently not due to excessive or unanticipated variation in height, apart from the association between it and any variable (see Table IV). The most probable cause of lack of association was failure to pick the best associated variable.

Topographic position (variable X_1), which proved to be closely related to growth in tulip poplar and sweet gum, was not an effective variable in southern red oak and white oak. This may mean that on slope sites the variability of tree site index for these oak species was not great. This is not entirely surprising, since these species were only occasionally encountered at the topographic extreme where tulip poplar and sweet gum made their best growth.

Site Productivity

Productivity seemed generally to be related to the coarser aspects of site associated with soil moisture. Topographic position and the degree of drainage were important indicators.

The consistency of the relations varied with the species. Relatively little of the variation of growth of southern red oak and white oak could be associated with site factor variation. The association was much stronger in tulip poplar, sweet gum, and cherrybark oak.

It was not apparent whether the relations found were functional. Of course, as far as prediction is involved, it does not matter as long as they

predict successfully and consistently. Even though the relation is not fully understood, it can be used.

Species composition was found to be associated with site productivity in a general way, but the relation could not be expressed with precision, so its usefulness in delimiting sites would not be great.

Indications were found that productivity was associated with soil series to a certain degree; so that, for example, growth of sweet gum on the average would be expected to be better on Ina and Beechy than on Memphis or Lexington. There was much overlapping of productivity ranges on different soil series so that series classification would not furnish a precise estimate.

Effects of environmental factors. It was concluded that among the species studied topographic position was the most important factor in site productivity. When tested for its correlation with tree site index, topographic position was significant in simple regressions with all four of the species in which it was tested. (It was disregarded in cherrybark oak because of probable bias of the sample.) Moreover, the more complex multiple regressions, when significant, usually included this variable in the combination.

Apparent surface drainage, another expression of the water regime, was the factor next in importance. As a single variable, the only species in which it was not significant was white oak. It gave an especially high mean square ratio in sweet gum and one fairly high in cherrybark oak. Drainage also proved an important ingredient of combinations of factors in multiple regressions in sweet gum and cherrybark oak, but not in tulip poplar

or white oak. With southern red oak, drainage class was the most important factor.

Other variables proving important were aeration porosity for tulip poplar; slope length, competition index, and soil depth to mottling for sweet gum; and basal area for cherrybark oak.

Some of the variables, while they did not show significant tests, did contribute an appreciable amount to the regression sum of squares. Thus in southern red oak, the only variable of significance in multiple regressions was drainage, and yet the addition of another variable, though it tested not significant, did raise the coefficient of determination from 0.128 to 0.159.

Suggestions for Future Studies

The study could be extended by covering more species. More of the critical species of the stand composition phase, and species of interest regardless of their commercial value, could be investigated.

The data on soils features related to the moisture regime could be strengthened by the use of field methods intended to test these features. Now that the extensive phase of the study has been passed, field sampling of soils specifically for the determination of moisture content, porosity, and for mechanical analysis would yield much stronger data.

The area studied was quite small. If predictive equations that apply to the study area alone can be derived from this work, the immediate objective of the study will have been fulfilled. These data, however, should apply to a larger area surrounding the Plantation, in the region of loess-derived soils in west Tennessee and probably in similar parts of

north Mississippi. Tests against local data would show the reasonable limits of application.

More soils, other soils, could be covered to make a fuller picture of productivity or to extend the range of productivity covered.

A whole segment of an experimental program could be built around the study of soil fertility levels and the growth of hardwoods. This subject was not touched in the present study.

A challenging and elusive problem concerns the effects of soils on wood quality. Timber buyers maintain that wood such as white oak is not necessarily of proper quality just because it is in a big tree on a site of high productivity. Some quality of the wood itself, they say, can vary independently of ordinary grade. Features of this sort, and the effect known as "mineral stain" associated with certain sites, would be fitting work for the study of the importance of soil characteristics in the growth of hardwood timber. Kruckeberg's analysis (1959) of the place of soil minerals in wood preservation shows the applicability of such studies in a related field.

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