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A Method of Classifying Shortleaf Pine Sites in Missouri

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SUMMARY

Three areas in Missouri were sampled to establish the relationship between site index of shortleaf pine and two topographic and three soil factors. The three areas were different geologically and this study attempts to determine whether the same independent variables can be used with equal confidence in areas which contain differences in soil type. A total of 309 plots was measured, being almost equally divided between the three areas which were: (1) Granite Hills, comprising St. Francois, Iron, and Madison Counties, (2) south-central Missouri, restricted to Oregon County, and (3) central Missouri, where the stands were measured in Dent County.

The two topographic factors used as independent variables were: (1) Slope and aspect combined into a single variable and (2) slope position.

The three soil factors were: (1) Texture of the B horizon, (2) stone content of the B horizon, and (3) consistence of the B horizon.

The field measurements and observation of the independent variables were evaluated according to their effect on soil moisture availability, as the central premise of the study is that soil moisture is a limiting factor in the growth of shortleaf pine in Missouri. The evaluation of the independent variables was accomplished in a rational and logical manner, adhering to the hypothesis that if soil moisture is limiting, it affects the biological processes of growth.

The appropriate ratings for each independent variable were applied to each plot measured in the field. These ratings were then subjected to a multiple regression analysis by an IBM 650 high-speed computer, using site index as the dependent variable. A regression analysis for every possible combination of the independent variables was achieved so that it was possible to determine which variable or combination of variables would result in the highest correlation which site index.

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ANDREW J. NASH[1]

INTRODUCTION

As one of the southern pine group, shortleaf pine *(Pinus echinata* Mill.) enters into the economy of many areas in the southern and southeastern states. Its economic importance is not as great as that of some of the other southern pine, but in localized areas it is the major source of lumber, poles, and fence posts.

The species reaches the northwestern limit of its botanical range in Missouri where it is confined to the south and southeastern portions of the state. Although the present area and volume of shortleaf pine in Missouri is not large, it has been a major timber-producing species. According to the recent (1959) Missouri Forest Survey, the volume and area of sawlog-sized stands of shortleaf pine have doubled in the past 12 years. These are the stands which replaced those cut at the beginning of the 20th century and which now are becoming merchantable.

The factors limiting the botanical range of shortleaf pine are partly geological and partly climatic. Fletcher and McDermott (1957) showed that climate plays an important role in the natural distribution and regeneration of shortleaf pine in Missouri. The species does not occur naturally where the winter (November to April) precipitation is less than 17 inches.

Southern Missouri has mild winters and warm summers. The average winter temperature is 33 degrees and that of summer is 74 degrees. The average annual temperature is 54 degrees and there are approximately 180 frost-free days. The average annual precipitation is 40 inches, of which 17 to 20 inches falls between November and April. The high average monthly temperatures during the summer months and the pattern of precipitation from April to September are responsible for high evapotranspiration losses and a drouthy condition of the soil.

Statement of the Problem

This study will use topographic and soil factors to estimate site index[2] for shortleaf pine in Missouri. Specifically, two topographic and three soil factors will be used in a statistical approach to establish the relationship between the independent and dependent variables.

In the Missouri Ozarks, a region characterized by summer drouths which are sometimes severe and prolonged, moisture supply to trees is limited and the

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[2]Site index is the average height of the dominant and codominant trees in a stand, referenced to a base age. In the mid-west, the base age is 50 years.

study of moisture relationships becomes one of more than passing interest. Initial survival and subsequent growth are closely associated with the struggle for moisture. Therefore, an evaluation of site based on topographic and soil factors should demonstrate that they have an effect on the availability of moisture.

In the Ozark region of Missouri to which this study refers, the amount of water available for plant growth is affected by one or more of the following:

1. Texture of the soil.
2. Structure of the soil.
3. Surface runoff.
4. Presence of a claypan.
5. Internal drainage.
6. Volume of stones or rock in the soil mantle.
7. Precipitation.
8. Depth of the soil mantle.
9. Interception of precipitation by the canopy and forest floor.
10. Organic matter content in the soil.

The physiographic factors associated with soil moisture area:

1. *Slope Position.* Except where there are rock outcrops close to the surface, soil depth generally increases down slope. A greater soil depth affords larger volume of moisture-holding components of the soil and greater depth for root penetration.
2. *Aspect.* The rate of soil moisture extraction by evaporation and transpiration is related to the intensity and duration of solar radiation. Extreme evapotranspiration rates occur on south and southwest aspects while a lesser rate occurs on north and northeast aspects.
3. *Degree of Slope.* The amount of solar energy received at the earth's surface varies not only according to aspect but also according to the angle at which the energy is received. Surface runoff and drainage are also affected by the degree of slope.

In addition to these topographic factors, three soil factors will be used because they influence the amount of moisture held in the soil, the rate at which moisture is removed, or the aeration of soil. It must not be assumed that the soil factors to be described are the only ones which influence the moisture relationships; there are others, but for purposes of this study, the following were measured and evaluated:

1. *Soil Texture.* An increase in the proportions of silt and clay in a soil increases the moisture-holding capacity.
2. *Stone Content.* A soil of a certain texture has an average moisture-holding capacity according to the amount of sand, silt, and clay it contains. If the soil

is stone-free, the moisture-holding capacity will be a maximum for its texture. However, if the soil mantle contains stones, the volume of soil available for water storage will be reduced accordingly.

3. *Soil Consistence.* Soil consistence is a term used to describe the physical condition and degree of compaction in a soil sample. Compaction in soils may be a limiting factor in the growth of vegetation by causing a reduction in the normal exchange of soil gases. Insufficient soil aeration can be as serious in the proper functioning of soils as insufficient moisture.

The problem to be solved is that of evaluating the factors listed above so that the values are consistent with their effect on soil moisture. To use a statistical approach to the study, qualitative data must be transformed into quantitative values.

Winter precipitation in southern Missouri is sufficient to recharge the storage capacity of the soils so that they are at field capacity at the beginning of the growing season (Nash, 1963). Thus, when the first flush of growth occurs, soil moisture is not a limiting factor. The study, therefore, is concerned with the effect of the factors listed above during periods when there is soil moisture stress. The amount of soil moisture available at the time vegetative buds are set in the fall undoubtedly has an influence on the amount of growth which will occur the following spring. Shortleaf pine growth is arrested when soil moisture supply is below a minimum level and is reactivated following precipitation which is sufficient to recharge soil moisture capacity, providing other growth conditions are satisfactory. The hypothesis that soil moisture is a limiting factor in the growth of shortleaf pine in Missouri has been made in the light of the above statements and assumptions.

REVIEW OF LITERATURE

In the late 1920's foresters and soil scientists in North America became interested in the physical factors that affected tree growth. Prior to that time it had been the soil physicist and soil chemist who had contributed most to the literature dealing with soil in relation to growth factors.

The works of Auten (1936), Billings (1938), Coile (1935), Diebold (1935), Joffe (1936), and of Turner (1937) are evidence of the interest taken by foresters in the problems of tree growth in relation to physical factors.

Coile (1935) concluded that subsoil characteristics can exert a very strong influence on the growth of shortleaf pine after it has passed the sapling stage. This study examined the relative effects of the depth of soil horizons, texture, porosity, water absorption capacity, and volume weight as independent variables affecting height growth. He could not isolate any single physical soil factor but concluded the texture of the B horizon, together with thickness of the surface layers, gave the highest correlation with site index.

In discussing the effect of topographic factors on site index, Turner (1938) determined that degree of slope was highly correlated with site index for loblolly pine in the coastal plain region of Arkansas. He also found that low site indices were indicative of poor internal drainage and excessive runoff. This investigation was one of the first to show the importance of a topographic factor as it influences site index.

Cooper (1942), however, came to the conclusion that there was no relation between site index of pine and aspect or slope in the Piedmont region where erosion of the upper soil surface had been prolonged and severe. He explains the lack of relationship by saying that the slopes are gentle and short. The same conclusion might not be expected to hold true in areas of more rugged topography. For an independent variable to show partial correlation at a significant level, it must *be* a variable, not a relatively static quantity. Cooper also states that "any method that centers on one factor to the exclusion of the others would not be entirely accurate." It is possible that a single site factor may be so strong in its correlation with site that it is actually a controlling factor. In this case, the evaluation of site would be accurate. To be accurate, a method must utilize those factors which are controlling.

Minckler (1943) found that shortleaf pine plantations in southern Illinois exhibited remarkably uniform height growth regardless of topographic location or seasonal precipitation. He argues that shortleaf pine growth is related to the depth of the A horizon, not to aspect, rainfall, or soil consistency. In this statement, he disagrees with a number of workers who have shown that aspect, as a topographic factor, does influence height growth. It must be realized, however, that Minckler is referring to plantations, not to natural stands.

On the subject of soil moisture in relation to site, Copeland (1955) indicated that an artificially-induced drouth on shortleaf pine had the effect of shortening shoot growth and needle length and that diameter growth was greatly reduced. Dingle and Burns (1954) determined that the moisture content in the upper 3 inches of the soil profile was not correlated with site quality for shortleaf pine in Missouri. The upper 3 inches of the soil profile is subject to great fluctuation in moisture content and it is understandable that no correlation was found.

Soil moisture content and the fluctuations it experiences are related to climate in general and to the precipitation pattern in particular. Climate plays an important role in determining the amount of water loss by evapotranspiration. Thornthwaite (1948) and Thornthwaite and Mather (1957) have dealt with the subject of evapotranspiration at length and their calculations are designed for computing the water balance under average physiographic conditions. Little water is actually used by vegetation for its growth processes; this is particularly true of trees. Budyko (1958) states:[3]

> "It should be noted, however, that extensive experimental data proved that vegetation also spends water resources in a very uneconomical way i.e. the productiveness of transpiration (the ratio of weight accumulation

[3]"The Heat Balance of the Earth's Surface". Translated from Russian by Department of Commerce, Washington, D. C. page 180.

> of dry mass in the plant to the discharge of water for transpiration during a certain time interval) is usually from 1/200 to 1/1000 (mostly about 1/300). It is just a useless waste of water."

Transpiration is essential to the life of the tree, but if all growth factors were at an optimum level, the rate of growth would maximize at some point regardless of how much water is used in the transpiration process.

Since the only available energy for evapotranspiration must originate with solar radiation, it follows that solar radiation is the logical basis for computing moisture losses from the soil. Swift (1960) gives figures for extra-terrestrial solar radiation receipt on horizontal surfaces and shows that various slopes and aspects modify the energy values received. Swift does not take into account the effect of cloud cover but has computed the energy received on the basis that there is no atmosphere to reduce the intensity of solar radiation. Geiger (1959), however, has studied the effects of cloud cover on solar radiation receipt and he shows that solar energy under a completely overcast sky is practically the same for all aspects.

For conditions of less than complete overcast, energy receipt varies according to aspect and time of year. Nash (1963) has shown that when solar radiation in southern Missouri is modified by average cloud cover, a steep north slope receives as much as 20 percent less radiation than a horizontal surface and a steep west slope receives approximately 15 percent more. Other aspects receive values between these extremes.

The effect of slope and aspect on solar radiation receipt is more pronounced when it is applied to water balance computations. Nash (1963) shows that a net soil moisture deficit exists for the growing season on a horizontal surface in southern Missouri. When slope and aspect are taken into account, the net soil moisture deficit for a steep north slope is reduced to approximately one-half that of a horizontal surface. On the other hand, the net soil moisture deficit for a steep west slope is approximately twice that for a horizontal surface. Even when the soil moisture storage value is liberally estimated (2.5 inches of water per foot of soil), a moisture deficit occurs on all slopes and aspects except that for a 50 degree north slope. For soil moisture storage values less than this, or during a year that is drier than normal, the soil moisture deficit is more apparent and more acute. The results given by Nash show that shortleaf pine is growing under rather adverse conditions as far as soil moisture availability is concerned.

AREAS EXAMINED

A detailed description of the areas examined is necessary in order to portray differences between them and to relate these differences to variations in site index. Primarily, the study areas were selected because of geological differences and

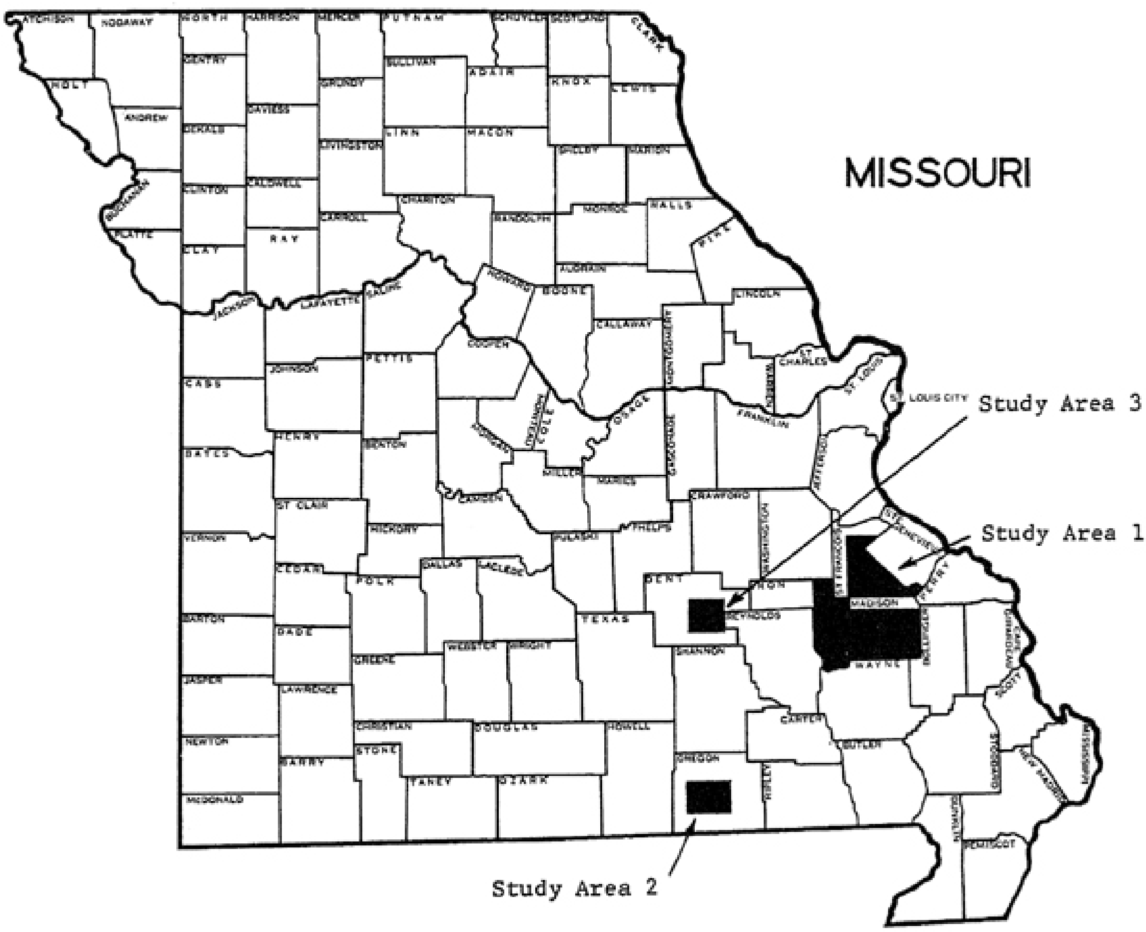

Fig. 1—Location of the three study areas.

the diversity of topographic conditions occurring within areas. Figure 1 shows the location of the three study areas.

Study Area 1: Granite Hills Region

An area containing a granite uplift is centered in St. Francois and Iron Counties. It is characterized by gentle to moderately steep slopes and some broad valleys caused by erosion of the sedimentary strata. As might be expected, the soil types in the area are numerous and, at times, difficult to classify because of "slumping." The granite knobs support very sparse vegetation while the valleys have long since been cleared and cultivated for farm crops. Shortleaf pine stands occur throughout the granite hills and on the steeper portions of the valley slopes.

The Ashe stony loam soil is characteristic of the granite hills region and is one of the poorest soils in the state from a fertility point of view. For a detailed description of the soils mentioned in this and succeeding sections, the reader is referred to "A Key for Identifying the Soils of Missouri" published by the Soils Department, College of Agriculture, University of Missouri. Miller and Krusekopf (1919) describe the Ashe stony loam as : ". . . a gray, very stony loam with yellowish clay subsoil containing considerable sand, stones and boulders. The soil is a silty loam. It washes easily. It is a cold natured soil." Since the soil washes easily, the fine fractions are deposited in the valleys.

The vegetation which is struggling for existence in the granite knob area is chiefly shortleaf pine, black oak, white oak (on the deeper, more moist soils down slope), red oak, post oak and hickory. Figure 2 shows shortleaf pine growing on an exposed granite knob.

The Hagerstown soil is characteristic of the valley soils; it is derived from a chert-free limestone and occurs mainly in the north-south valleys of the area. It is a silt loam with a brown to reddish-brown surface soil that is 8 to 14 inches deep. The subsoil is characteristically a brown to dark reddish brown silty clay. In the simplified classification system developed by the author, the identifying features of the Hagerstown soil are:

1. Soil not stone-free.
   a. Subsoil color red or reddish-brown.
      a.1. Very few stones. HAGERSTOWN

A complete classification of the Ozark soils according to the author's system is given in the Appendix (Table 18) and reference will be made to it in relation to other soils encountered.

Brydon and Marshall (1958) describe the genesis of the Hagerstown soil. They state that it occurs in a region of transition between the gray-brown podzolic soils of the north and the red and yellow soils of the south. Some authors include the Hagerstown in a completely separate grouping and the literature gives supporting evidence for both views.

Other soils are found in the Granite Hills region but are not characteristic of it; they will be described in detail in the sections dealing with the other two areas studied. As one traverses the area, the following soils may be encountered: Tilsit, Eminence, Clarksville stony loam, Clarksville gravelly loam and Lamotte. Due to the violent upheaval caused by the granite uplift, these soils are not found in any definite order but are associated with the geologic strata. An illustration of a slow-growing shortleaf pine on Lamotte silt loam is shown in Figure 3.

Study Area 2: Oregon County

Oregon County is situated in the south-central portion of the pine growing region of the state. There have been no major geologic disturbances to affect the normal erosion process which has formed deep valleys dissecting the landscape. There are three main geologic strata in the area, the Jefferson City, the Gasconade, and the Rubidoux.

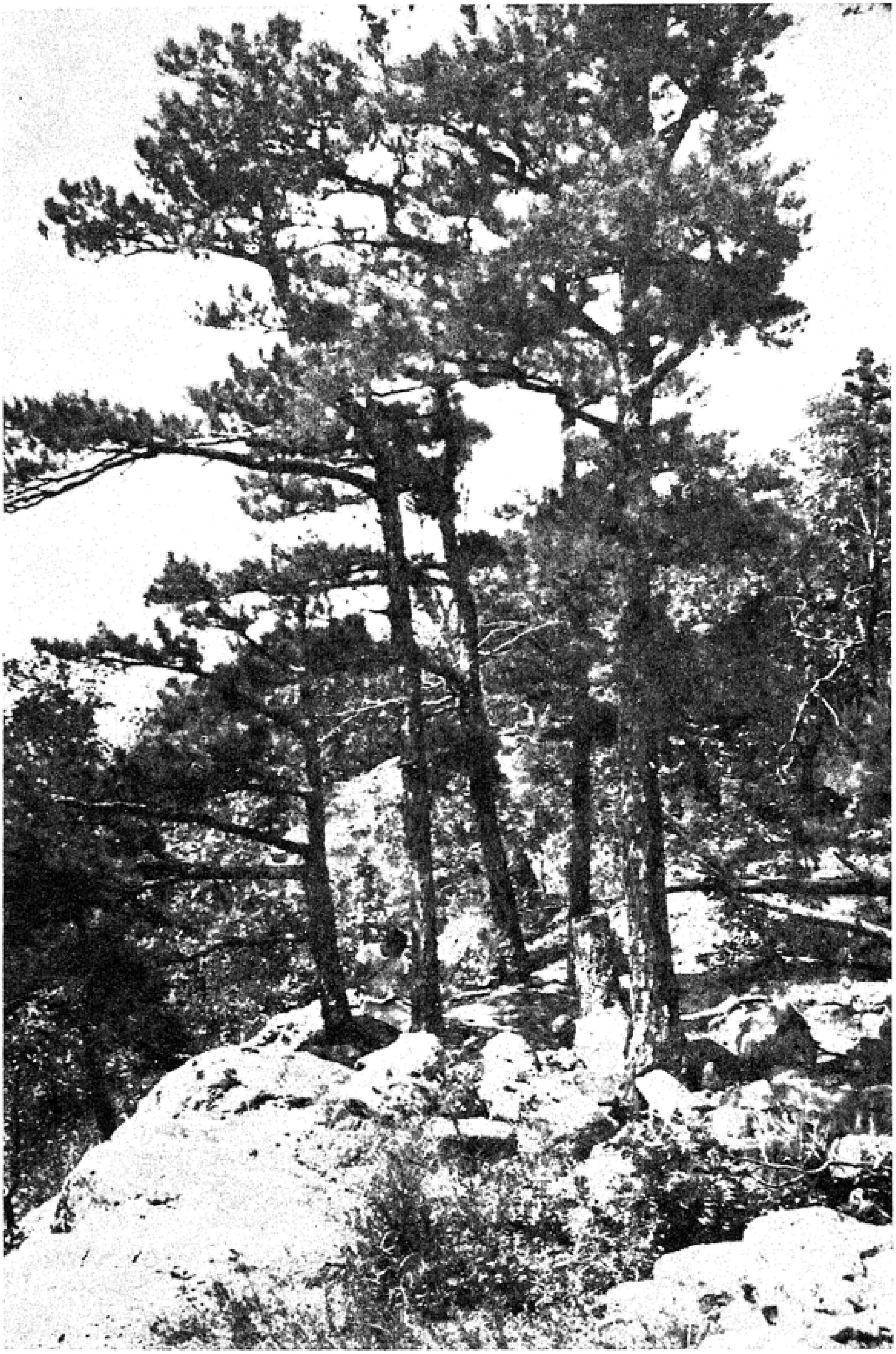

Fig. 2—Shortleaf pine on exposed granite knob.

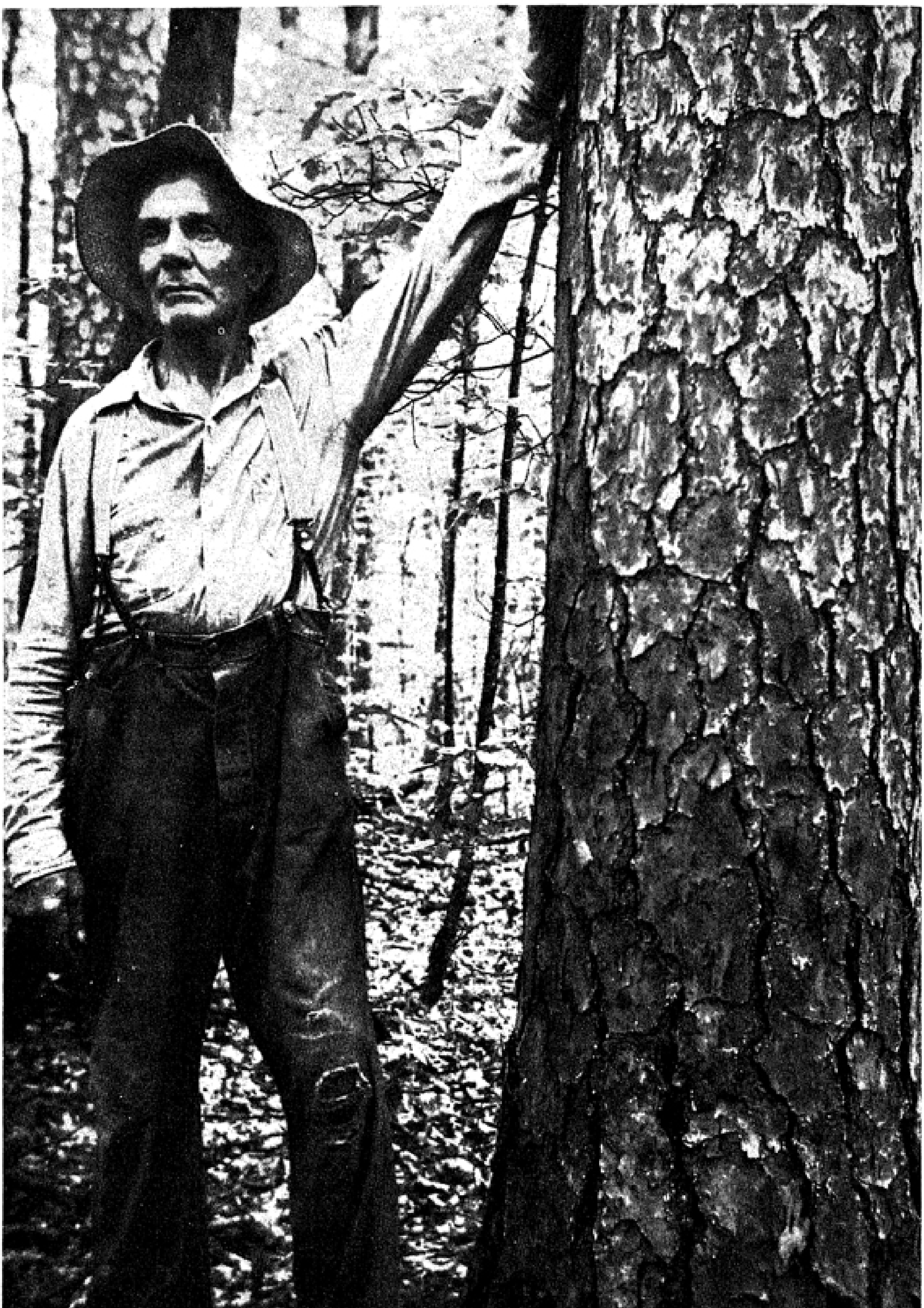

Fig. 3—Mature shortleaf pine, 21.0 inches in diameter and 98 feet in height. Note "alligator" bark, typical of slow-growing shortleaf pine. Southeast Missouri.

The Rubidoux and Gasconade form the predominant part of the Ozark surface rock outcrops while the Jefferson City formation prevails on uplands throughout the periphery of the Ozark province.

The characteristic soil is the Clarksville which is keyed out as follows:

1. Subsoil color not red or reddish brown.
   - a. Northern and Eastern Ozark border areas.
   - b. Ozark region.
     - b.1. Soils derived from granite.
     - b.2. Soils not derived from granite.
       - b.2.1. Subsoil color yellow. CLARKSVILLE

The forest vegetation on the south and southwest exposures is relatively light compared to those of the north and northeast; consequently, they are subject to greater runoff, resulting in a stony condition. An illustration of the stony surface of the Clarksville soil is shown in Figure 4. The predominant stone in the soil is chert, derived from the cherty limestone of the Gasconade formation; numerous sandstone rocks are present also, being derived from the Rubidoux formation. Generally speaking, the Rubidoux formation covers the greater portion of this area of the Ozarks. The soil varies from a sandy loam to a silt loam on the surface and from a silt loam to a silty clay loam in the subsoil; its characteristic color is a light yellowish brown.

Fig. 4—Stony surface of Clarksville soil on a 50 percent southwest exposure. Oregon County, Mo.

Study Area 3: Dent County

The topography of Dent County, located near the northern botanical limit of shortleaf pine in Missouri, does not present such contrasts as occur in the two areas mentioned previously. The peneplain is not so deeply dissected and the hills are more rounded.

An outstanding feature of this area is the presence of a highly-weathered layer of silt on the broad ridge tops. It is thought that the silt was deposited in geological times by deposition of wind-blown material from the central plains region. Accumulation of decomposition products in the form of clay has resulted in a pan layer approximately 18 inches below the surface. The ridge soil is classed as the Lebanon silt loam and, in the words of Miller and Krusekopf (1919) ". . . the Lebanon silt loam probably has more unfavorable subsoil characteristics than any Ozark soil."[4] Fortunately, the area occupied by the loessial soil is relatively small, being confined to the main ridges and some spur ridges.

The greater portion of the shortleaf pine stands in this area occupy the Clarksville stony loam, derived from cherty dolomitic limestone. The subsoil texture is a sandy to silty loam where the underlying rock is sandstone or a silt loam to silty clay loam if limestone is the parent bedrock.

Occasionally, the subsoil is a silty clay and relatively stone-free; its origin is an outcropping of a chert-free dolomite which is a rarity in this locality. One such example (see Figure 5) contained an average stone content of 15 percent to a six-foot depth. The higher clay content, with its increased moisture-holding capacity, resulted in the shortleaf pine having better growth than on adjoining areas. These deep clay pockets are not numerous but from an interesting comparison with the characteristic Clarksville soil series.

METHODOLOGY

The following sections deal with the method of obtaining the field data (Part I), of evaluating the measurements for the purpose of assigning numerical values to qualitative data (Part II) and the methods of analyzing the data by the use of a multiple regression analysis by an IBM computer (Part III).

Field Data

Method of Stand Selection. The objective of stand selection was to obtain data that were representative of as many variations in topography and stand ages as possible, since the "independent" variables in the multiple regression analysis were to be based partly on topographic and partly on soil factors. The topographic conditions were the main criteria for stand selection, whereas the soil factors were measured as they occurred within topographic classes.

The basic unit of measurement was a strip parallel to contour lines and occupying the same topographic location; the strip was as long as necessary to obtain height-age and other data from at least seven dominant and codominant

[4]Mo. Agr. Exp. Sta. Bull. 153. p. 69.

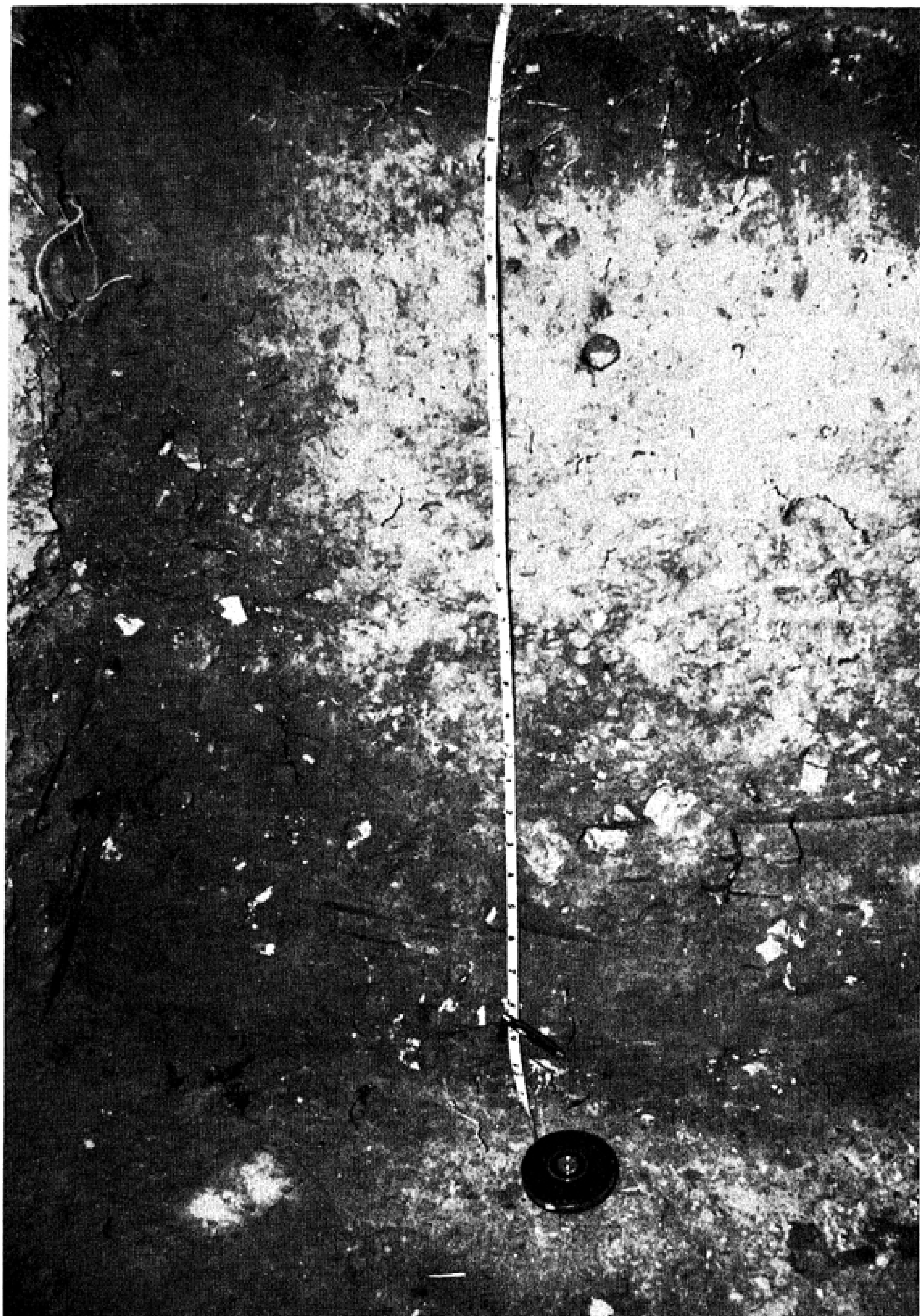

Fig. 5—Three-foot soil profile in a high-clay pocket. A hole was drilled another three feet in the center of the pit; Clay content increased slightly with depth. Dent County, Mo.

shortleaf pines. The width of the strip varied according to density of the stand but was seldom greater than one-half chain wide. Thus, the unit of field measurement was of no definite size. Since the study was interested in the effect of various topographic and soil factors on growth, it was felt that there was no necessity to obtain a tally of the number of trees per acre or to obtain an estimate of stand density. Mann and Whitaker (1952) have shown that, with site being held constant, stand density has only negligible effect on height growth. It is recognized, however, that height growth is affected by extremes of density and for this reason, extremely dense and open-grown stands were avoided.

Figure 6 shows the topography surrounding a valley in Oregon County, south-central Missouri. The location of some of the measurement areas are indicated to illustrate that the basis for stand selection was mainly topographic. This particular valley was ideal in that practically pure shortleaf pine stands occupied all aspects, all degrees of slope from level to very steep, and all slope positions from lower to upper slope. Not all areas were this ideal.

A field data sheet was designed to record the necessary information. An important feature of the data sheet is the description of the soil from observations and measurements taken from a soil pit. This established the soil series, percent of rocks and stones in each horizon, the textural class (which was later verified or changed after running texture determination in the laboratory, using the standard Bouyucous method), structure, and consistency of each horizon. The importance of these soil characteristics will be emphasized in a later section.

In addition to a soil description, a topographic location description was recorded, according to aspect, slope and slope position. Aspect was designated by 45-degree classes, (north, northeast, etc.), and slope was measured with an Abney hand level by 5 percent classes. Slope position was described as upper one-third, middle one-third, lower one-third, ridge top, saddle etc.

The following data were taken on the dominant and codominant trees selected as being representative: Total age in years at stump height, total height in feet, length of live crown, crown ratio, and radial growth from the pith by 10-year periods. The maximum height difference between trees in the same stand was approximately 15 percent of total height, with most falling within 10 percent. The ruling consideration was that the trees had to be on the same topographic location.

U.S.D.A. Bulletin 50 (1929) gives site index curves for shortleaf pine; however, the distribution of sample trees measured for these curves covers a very wide area of its natural range, with relatively few trees being measured in Missouri. Since the field work covered three separate areas in Missouri, it was felt that empirical site index curves should be constructed and used as the basis for the dependent variable. The general method of constructing the site index curves followed the procedure outlined by Meyer (1953); harmonization of the curves was accomplished by the method proposed by Dwight (1937). The site index curves for each area are included in the Appendix as Figures 11, 12, and 13.

For the stands measured in the Granite Hills region, 484 trees were available for site index calculation. They ranged in age from 18 years to 110 years

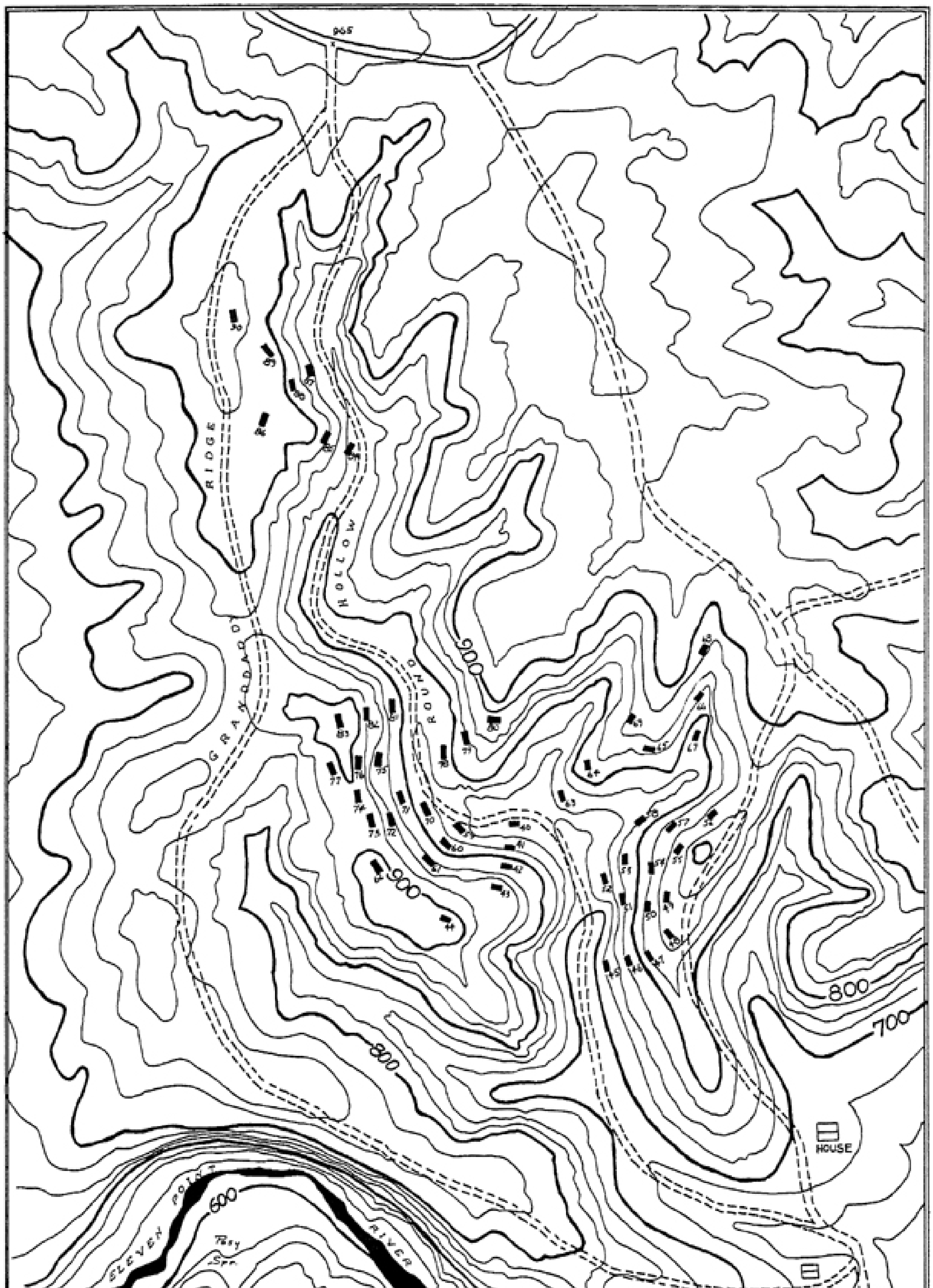

Fig. 6—Topographic map showing valley and surrounding terrain with location of measurement areas. South-central Missouri (Oregon County). Scale: 1:10000.

and were well-distributed as to age class representation. The average site index for all stands in this region was 52, calculated on a base age of 50 years.

In Oregon County, south-central Missouri, a total of 651 trees was measured. The age-class distribution showed evidence of past cutting and of fires, since most of the trees were in the 30-year and 40-year old classes. This made the curve rather unbalanced but representative stands from other age classes permitted the establishment of a reasonably strong age-height relationship. The average site index was 53.

In Dent County, the history of shortleaf pine is well-known. Logging in the area commenced about 1920 and was mainly for the prime hardwoods. Removal of the hardwood stands and subsequent fires initiated stands of shortleaf pine, which in some cases, became mixed with hardwoods. The age-classes are quite restricted; only three age classes are represented, the 30-, the 40- and the 50-year classes. It was felt that, despite the scarcity of age classes, the empirical site index curves were a truer representation of the age-height relationship than that contained in U.S.D.A. Bulletin 50.

Assigning Numerical Ratings to Qualitative Data

To obtain partial correlation coefficients through multiple regression analysis, the qualitative data described and recorded in the field must be transformed into numerical ratings consistent with their effect on available soil moisture.

Soil moisture is affected by one or more of the following:

1. Slope.
2. Aspect.
3. Slope position.
4. Soil texture.
5. Soil structure and consistence.
6. Stone content.
7. Amount of precipitation.
8. Amount of organic matter.
9. Rate of evapotranspiration.

The development of ratings or index numbers for the first six factors will be discussed in the succeeding sections. It is realized that the last three do affect the amount of moisture in the soil at a given time but no specific data are presented for them individually. The independent variables for which index numbers are to be developed are:

(1) Slope and aspect,
(2) soil texture,
(3) stone content,
(4) slope position, and
(5) soil consistence,

in the order listed.

Slope and Aspect and Their Relation to Available Soil Moisture. These two factors are so closely related that they must be considered together. The logical starting point is to review the relationship between receipt of solar radiation and evapotranspiration. The rate of evapotranspiration is affected by the duration and intensity of solar radiation and the soil moisture content. As the soil moisture content decreases, the rate of moisture loss is also decreased due to greater tension between the soil-water interfaces. At the wilting point, most vegetation is unable to extract moisture because the absorbing roots are not able to overcome a tension greater than 15 atmospheres, which is considered to the limit of a tree's capabilities.

Nash (1963) presents tables which give the expected solar radiation by slope and aspect in southern Missouri during a normal growing season (April to October inclusive) Cloud cover, which reduces the effect of aspect, has been taken into account in his study. The use of solar radiation rather than soil moisture deficits eliminates the possibility of confounding the issue, since soil depth and stone content also affect soil moisture content. Actual solar radiation expected on different slopes and aspects is a definite value which can be calculated to a reasonable degree of precision.

A slope which receives more solar radiation than another has a greater potential for losing soil moisture by evapotranspiration; it is assumed that the difference in moisture loss depends on the relative amounts of energy received.

The following tables of solar radiation receipt by slope and aspect are quoted from Nash's results and will form the basis for evaluating the effect of these two topographic factors. The values given in Table 1 are extra-terrestrial values corrected for cloud cover only; they have not been corrected for other atmospheric losses.

TABLE 1 - VALUES OF SOLAR IRRADIATION RECEIVED BY SLOPE AND ASPECT FOR AN AVERAGE FROST-FREE SEASON AT A LATITUDE OF 37 DEGREES NORTH

Slope degrees	Aspect (gm-cal/sq.cm/day)							
	N	NE	E	SE	S	SW	W	NW
10	538	545	548	575	568	562	562	545
20	525	530	569	602	575	591	583	530
20	526	532	578	616	596	613	580	548
40	512	516	622	666	630	666	612	534
50	484	545	706	696	696	706	698	528

Assuming that a steep (50 degrees) southwest slope represents the poorest soil moisture regime, it should be rated the lowest in regard to its ability to supply moisture for tree growth. Conversely, a steep north slope represents the best moisture regime and should receive a maximum rating. The steep southwest slope received an average of 706 gm-cal/sq.cm/day of solar energy whereas a steep north slope receives 484. To rate the north slope in terms of southwest energy receipt, the following calculation can be made:-

$$\frac{\text{Energy received on southwest slope}}{\text{Energy received on north slope}} = \frac{706 \text{ gm-cal/sq/day}}{484 \text{ gm-cal/sq/day}} = 1.46$$

Values between the extremes were calculated in a similar manner (Table 2).

TABLE 2 - SOLAR IRRADIATION RECEIPT BY SLOPE AND ASPECT AS A RATIO OF THAT RECEIVED ON A SOUTHWEST 50 DEGREE SLOPE

	Aspect							
Slope degrees	N	NE	E	SE	S	SW	W	NW
	ratio 1:							
10	1.31	1.30	1.27	1.25	1.25	1.26	1.26	1.30
20	1.34	1.33	1.25	1.18	1.25	1.20	1.22	1.33
30	1.34	1.33	1.22	1.11	1.18	1.16	1.22	1.27
40	1.39	1.35	1.11	1.06	1.13	1.06	1.16	1.33
50	1.46	1.30	1.00	1.01	1.01	1.00	1.01	1.33

For purposes of coding, 1.00 can be subtracted from each item in the table, the remainder multiplied by 100 and the result rounded off to the nearest 5. Thus, for the value 1.31, the coded value would be 100 (1.31-1.00) = 31, which is then rounded off to 30. The coded values are given in Table 3.

For a horizontal surface, the coded value would be 20 since the solar radiation receipt is 602 gm-cal/sq.cm/day.

TABLE 3 - CODED VALUES OF SOLAR IRRADIATION RECEIPT BY SLOPE AND ASPECT BASED ON THAT RECEIVED BY A SOUTHWEST 50 DEGREE SLOPE

	Aspect							
Slope degrees	N	NE	E	SE	S	SW	W	NW
10	30	30	25	25	25	25	25	30
20	35	35	25	20	25	20	20	35
30	35	35	20	10	20	15	20	30
40	40	35	10	5	15	5	15	35
50	50	30	0	0	0	0	0	35

Slopes were measured in percent during the field work, therefore degrees of slope had to be converted to percent slope. Figure 7 shows the relationship between the rating and percent slope for an east aspect; the known points on the curve were taken from 0, 10, 20, 30, and 40 degree slopes which correspond to 0, 20, 35, 60, and 85 percent slopes. This permitted the rating of slope percent by 5 percent steps. All other aspects were treated in a similar manner but are

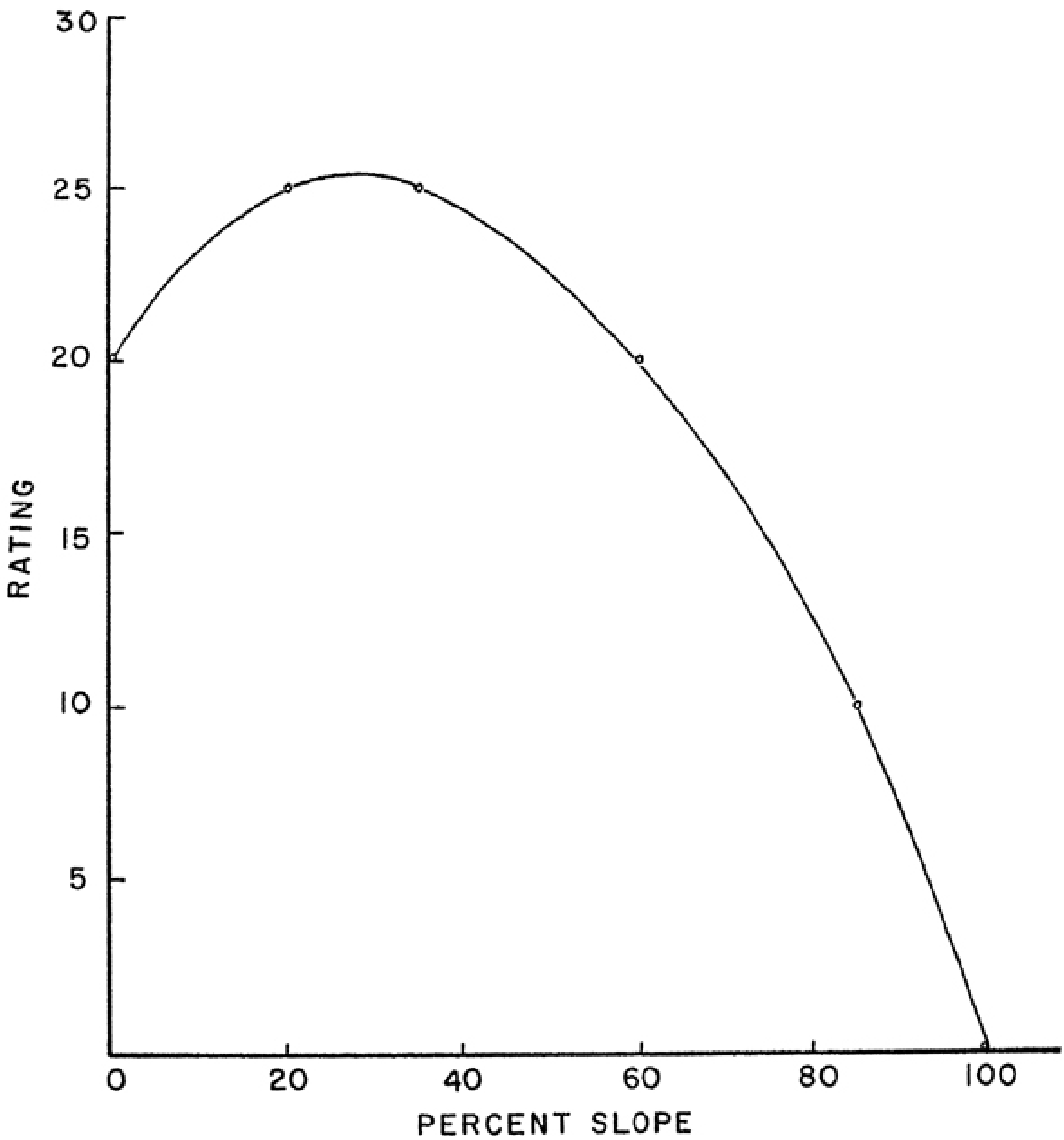

Fig. 7—Rating of slope and aspect by percent slope for an east aspect.

not shown. The complete table of ratings based on solar radiation receipt by aspect and slope is in Table 4.

The table of ratings might seem cumbersome and lengthy, but if the intention of obtaining a numerical rating for slope and aspect is to be realized, each combination of slope and aspect must be assigned a value which is indicative of the rate of moisture loss and thus the duration and intensity of moisture stress.

Soil Texture and its Effect of Available Soil Moisture. The moisture-holding capality of a soil is related to, among other factors, the size of the pore spaces

TABLE 4 - RATINGS BASED ON SOLAR IRRADIATION RECEIPT BY PERCENT SLOPE AND ASPECT FOR A LATITUDE OF 37 DEGREES NORTH

	Aspect (relative rating)							
Slope percent	N	NE	E	SE	S	SW	W	NW
0	20	20	20	20	20	20	20	20
5	23	23	22	22	22	22	22	23
10	26	26	23	23	23	24	23	26
15	28	28	24	24	24	25	24	28
20	30	30	25	25	25	25	25	30
25	32	32	26	24	26	24	24	32
30	34	34	26	22	26	22	22	34
35	35	35	25	20	25	20	20	35
40	35	35	24	18	24	18	20	35
45	35	35	23	16	23	16	20	33
50	35	35	22	14	22	17	20	31
55	35	35	21	12	21	16	20	30
60	35	35	20	10	20	15	20	30
65	36	35	18	9	19	12	19	31
70	38	35	16	7	18	10	18	32
75	39	35	15	6	17	8	17	34
80	40	35	12	5	15	5	15	35
85	40	35	10	5	15	5	15	35
90	42	35	7	3	11	3	11	35
95	44	35	4	2	5	2	5	35
100	45	35	0	0	0	0	0	35

between individual soil particles. The smaller the size of the pore spaces, the greater is the capacity of the soil to hold moisture against the force of gravity.

Moisture-holding capacity is normally defined as the number of inches of water that a soil of a certain depth will hold. This includes capillary as well as hygroscopic moisture but excludes gravitational moisture, since the measurements are taken after a saturated soil is allowed to drain for at least 24 hours.

The Forestry Handbook (1955) gives the moisture-holding capacity of various textures per foot of depth. Instead of including the hygroscopic moisture, the list contains only the capillary moisture. It is as follows:

Fine sand	0.5 inches per foot
Sandy loam	1.7
Silt loam	2.5
Loam	3.3
Clay	4.5

Other textural classes may be assigned moisture-holding capacities according to the percentage of sand, silt and clay they contain.

A rating of available soil moisture based on the capacity of the soil to store capillary water can be determined by giving the lowest rating to the soil which has the lowest moisture-holding ability; similarly, the soil which has the highest capacity would receive the highest rating. At this point, we are concerned only with the absolute moisture-holding capacity, not with the question of whether the moisture in the soil is actually used by the plant, or the rate at which it moves through the soil.

Table 5 shows the texture, absolute moisture-holding capacity and rating of soils based on the principles outlined above.

TABLE 5 - RATING OF OZARK SOILS BASED ON TEXTURE AND MOISTURE-HOLDING CAPACITY

Texture	Moisture-Holding Capacity per Foot	Rating
	inches	
Fine sand	0.5	1
Sandy loam	1.7	3
Sandy clay loam	2.0	4
Silt loam	2.5	5
Loam	3.3	6
Clay loam	3.5	7
Silty clay	4.0	8
Clay	4.5	9

Stone Content and its Effect on Moisture-Holding Capacity. The general effect of stones in the soil mantle is to reduce the volume of soil particles in a given depth. The size of the reduction will depend on the quantity of stones per unit volume, the distribution of sizes and shapes of stones and, to a limited extent, the moisture content of the stones themselves. In areas where stones constitute a large portion of the soil profile, trees must utilize a larger soil volume in order to obtain the same amount of water. The wilting point of the soil with high stone content is reached more quickly.

An independent investigation was carried out to determine the effect of stones on the moisture-holding capacity of soils. Figure 8 shows the proportional relationship. Thus, a soil with 50 percent of the mantle occupied by stones has a 50 percent reduction in moisture-holding capacity. A separate rating of stone content is proposed since the variability in stone content and texture would make a composite rating based on texture and stone content extremely complicated.

As the effect of stone content is proportional, a rating based on stone content alone can be easily derived; it is shown in Table 6.

Slope Position as it Affects Available Soil Moisture. The effective depth to which tree roots are able to extract moisture from the soil determines, to a great extent, the amount of moisture which is potentially available for growth and respiration. Shortleaf pine develops a taproot early in life, but the majority of feeding or absorptive roots are within the top 12 inches of the soil.

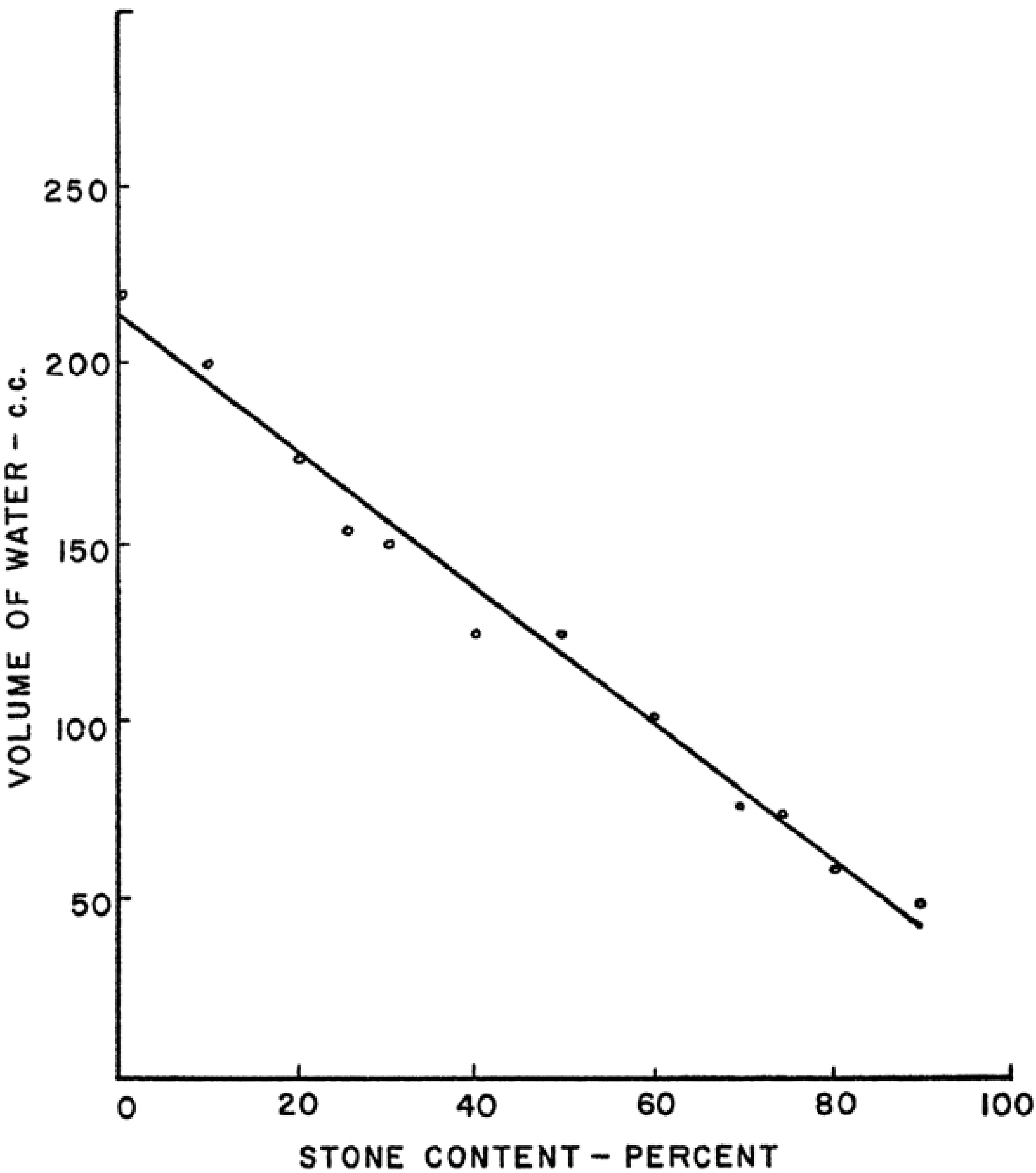

Fig. 8—Relation between volume of water necessary to fulfill capillary action and stone content in percent.

The effect of slope position on the growth of trees is primarily a matter of soil depth, which, in turn, influences the volume of soil from which roots can extract nutrients and moisture. Physical and chemical weathering of parent material, continuing for many thousands of years, have established certain equilibria in the soil. The soil may be considered to be in equilibrium with the climatic, edaphic, and biotic environment in which it is found.

Wilde (1958) has pointed out that as slope position changes from a ridge top through to a lower slope, the moisture content at field capacity increases because of increased volume of soil. He emphasized the importance of considering

TABLE 6 - RATING OF STONE CONTENT AS IT AFFECTS MOISTURE-HOLDING CAPACITY OF SOILS

Stone Content (percent total volume)	Rating
0	10
10	9
20	8
30	7
40	6
50	5
60	4
70	3
80	2
90	1

aeration and moisture together This is illustrated by the fact that tree height growth in wet depressions or in areas which have a high water table is reduced due to poor aeration.

Lutz and Chandler (1946) give a classification of soil depth as follows:

Very shallow	—0 to 6 inches
Shallow	—6 to 12 inches
Moderately deep	—12 to 24 inches
Deep	—24 to 48 inches
Very deep	—over 48 inches.

As they point out, soil depth is normally defined as including the combined A and B horizons, but excluding the C horizon or parent material. They state further, however, that foresters may find it convenient to add the additional component of the C horizon in defining soil depth, as many deep-rooted species can draw moisture from the lower levels.

Based on Lutz and Chandler's scale of soil depth, practically all the Ozark soils should be classified as "Very shallow" or "Shallow" since the combined depth of the A and B horizons rarely exceeds 12 inches. It seems advisable to follow their suggestion of a soil depth classification based on three horizons, rather than on two.

The depth classification that is being presented is as follows:

Designation	Depth
Shallow	up to one foot
Medium deep	from 1½ to 2½ feet
Moderately deep	from 2½ to 3½ feet
Deep	from 3½ to 4½ feet
Very deep	over 4½feet

In addition to those listed above, one more should be added to describe the special situation covering soils on ridges which are underlain with a pan; it may be described as "Shallow over pan." The pan is not cemented but consists of a stiff, massive, silty clay which does permit some drainage but very little root penetration.

The soils on the ridges are thin; not more than eight inches of soil is present on most ridges. Many instances were found in which the soil depth was not more than 4 or 5 inches above the pan layer. The average effective soil depth is approximately 6 inches.

On the shoulders of the ridges and the upper slopes, the soil depth averages 1 foot, ranging in depth from 8 inches to 15 or 16 inches.

On the mid-portions of the slopes, the soil mantle increases in depth and becomes quite well drained. The C horizon varies in structure from a massive, slightly compact silt loam to a granular, friable sandy loam with good aeration and internal drainage. The average soil depth on this topographic location is approximately 2 feet.

The lower one-third of slopes have benefitted by the accumulation of silt and clay which have been brought down by erosion from the upper portions of the slopes. A considerable amount of "slumping" has occured in the Ozark region, resulting in an enriched, deeper soil on the lower slopes. The dividing line between mid- and lower slopes is difficult to define accurately, but it may be taken as the point which includes the change in gradient from the mid-slopes to the bottom. The depth of the soil mantle at this location is approximately 4 feet and the soil is normally well-drained. The C horizon is inclined to have a higher content of silt and clay and is therefore of a massive, slightly compact to compact to compact structure.

Stream bottoms constitute a separate topographic situation when considering effective soil depth. Ninety-nine percent of the streams in the Ozark hills are intermittent and flow only after periods of heavy precipitation. However, stream bottoms represent the most favorable situation regarding soil depth and moisture availability. The effective depth of the soil is greater than 4 feet and in some instances has been found to be 10 to 12 feet. For purposes of delegating a depth class to the stream bottoms, the figure of five feet will be used; this class may be called Very Deep.

Shallow soils over bedrock present a somewhat different situation than shallow soils over a pan. The limestone and sandstone outcrops are generally well-fractured, allowing root penetration beyond the depth to actual bedrock. Naturally, the volume of soil retained in the rock fractures is small and would not add greatly to the actual depth. In these cases, the effective soil depth may be classed as the equivalent of 2 feet of soil, even though the actual depth may be much less.

Based on the information given above, a rating of soil depth as it is affected by slope position may be determined, with a "Shallow-over-pan" soil receiving the lowest rating. The data in Table 7 gives depths and ratings for gentle slopes; for the purpose of definition, a gentle slope is one which does not exceed 15 percent.

Soil erosion is closely associated with degree of slope. Conner et al. (1930) found that loss of soil through erosion was directly related to steepness of slope.

The ratings given in Table 7 were, as indicated, applicable to soils on gentle slopes. In situations where the slope changes to moderately steep, steep, or very steep, the same ratings would not necessarily apply, since erosion becomes an increasingly important function of slope. Field observation has shown that effective soil depth decreases with an increase in slope, justifying a revision of ratings according to percent slope.

TABLE 7 - EFFECTIVE SOIL DEPTH AND RATING BASED ON A SHALLOW-OVER-PAN SOIL ACCORDING TO SLOPE POSITION

Slope Position	Depth class	Effective depth	Rate
		feet	
Main and spur ridge	Shallow over pan	0.5	1
Upper one-third	Shallow	1.0	2
Middle one-third			
Shallow over-bed-rock	Medium deep	1.0	4
Lower one-third	Deep	4.0	8
Stream bottom	Very deep	5.0	10

Classifying slope by percent results in the following:

Gentle	— 5 to 15 percent
Moderate	— 15 to 25 percent
Steep	— 25 to 50 percent
Very steep	— over 50 percent

TABLE 8 - RATING OF SLOPE POSITION ACCORDING TO SLOPE POSITION AND GRADIENT

	Slope class				
Slope position	Flat 0-5%	Gentle 5-15%	Moderate 15-25%	Steep 25-50%	Very steep 50%+
Ridge	1	*	*	*	*
Upper one-third	*	2	2	1	1
Saddle	2	2	*	*	*
Middle one-third Shallow over bed-rock	*	4	2	1	1
Lower one-third	*	8	4	2	1
Stream bottom	10	10	*	*	*

*The slope positions for which no ratings are shown do not normally occur on the slope classes indicated.

Zahner (1957), in a study conducted in southern Arkansas on soil-site classification for upland pine, divided topograpy into gently, moderate, and steep slopes according to the degree of slope. The classification of slope used in this paper was derived independently and very closely approximates the equivalent values shown by Zahner.

An example of the revised ratings applied to a hypothetical situation follows:

> The effective soil depth on a gentle lower slope is 4 feet; this receives a rating of 8 from Table 7. If the slope position remains the same, but the slope increases to a moderate slope (15 to 25 percent), the effective depth would be comparable to a middle one-third on a gentle slope and would receive a rating of 4, since the depth of the latter topographic position is 2 feet. Similarly, the lower slope on a steep gradient would be comparable to an upper one-third on a gentle slope and would receive a rating of 2. If the stand were on a very steep slope (over 50 percent gradient), erosion would have reduced the soil depth to that comparable to a ridge type situation.

Table 8 shows the completed ratings of slope position according to percent slope.

Soil consistence and its influence on soil aeration. Baver (1959)[5] stresses the importance of soil air to plant growth as follows:

> ". . . restricted soil aeration (1) is the greatest limiting factor in the development of an extensive root system, (2) impairs the essential process of respiration of an established root system which retards both water and nutrient absorption and (3) prevents the orderly functioning of essential biological processes associated with good soil fertility".

The question of the potential water-supplying ability of a soil has been covered in the section of this paper entitled "Soil Texture and its Effect on Available Soil Moisture." This section is more concerned with the effect of inadequate aeration on plant growth.

Consistence is a term used to describe the internal forces of cohesion which hold aggregates together and external forces of adhesion which bind one aggregate to another. It is a qualitative term describing the degree of (or lack of) compaction of the soil, and it ranges from complete dissociation of particles as in sand to a highly compacted clay.

Consistence is associated with texture to some extent, as shown by Coile (1952). In well-drained soils, he associated consistence with texture as follows:

Consistence when wet	Texture	
Very friable (noncoherent)	Sands	
Friable	Loamy sands Light sandy loams	Loams
Semi-plastic	Sandy clay loams	Clay loams
Plastic	Sandy clays Silty clay loams	Clays

[5]Soil Physics, John Wiley and Sons Inc. New York, page 199.

Compaction of soils results from a number of causes; the effect of compaction is to cause a breakdown in natural structure and reduce the volume of non-capillary pores. In surface soils, man's activities and grazing cattle are the chief agents of compaction, whereas, in subsoils, compaction is more a result of chemical weathering and illuviation. The other causes mentioned also operate on subsoils but to a lesser degree.

Broadfoot and Burke (1958) show that an index of soil aeration may be obtained by subtracting the volume of water in soil from the total pore volume after it has been subjected to ⅓ atmosphere of tension. The result is called drainage capacity. The volume of water in a soil at ⅓ atmosphere of tension is regarded by many soil scientists as the equivalent of field capacity. Another vaule often used to obtain field capacity is the moisture in a soil which has been subjected to 0.06 atmospheres of tension. This figure is frequently given as 60 cm. of tension.

From an examination of a large amount of data collected from various localities, Broadfoot and Burke (1958) have associated drainage capacity with texture for surface and subsoils. Since subsoils are more stable and are not influenced to such an extent by organic matter as are surface soils, the data that will be presented refer only to subsoil conditions. Broadfoot and Burke (1958) give data for the mean and standard deviation of drainage capacity by textural groups such as coarse, medium, and fine-textured subsoils. Since drainage capacity is a direct measure of aeration and an indirect measure of degree of compaction, it will be assumed that the range of values covers soils varying from friable to compact. The drainage capacity of friable soils will be taken as the mean value plus its standard deviation, while that for compact soils will be the mean value minus the standard deviation. Table 9 gives the data from Broadfoot and Burke (1958)[7] on the left-hand side and the maximum, average, and minimum values corresponding to friable, average, and compact soils on the right.

TABLE 9 - DRAINAGE CAPACITY DATA FOR DIFFERENT SOIL TEXTURE CLASSES

Texture Class	Average Texture	Drainage Capacity		Drainage Capacity		
		Mean	Std. dev.	Max.	Average (percent)	Min.
Coarse	Loamy sand	31	7	38	31	24
Medium	Loam	20	14	34	20	6
Fine	Clay loam	6	5	11	6	1

[6]U.S.F.S. So. For. Exp. Sta. Occ. Paper 166, page 12.

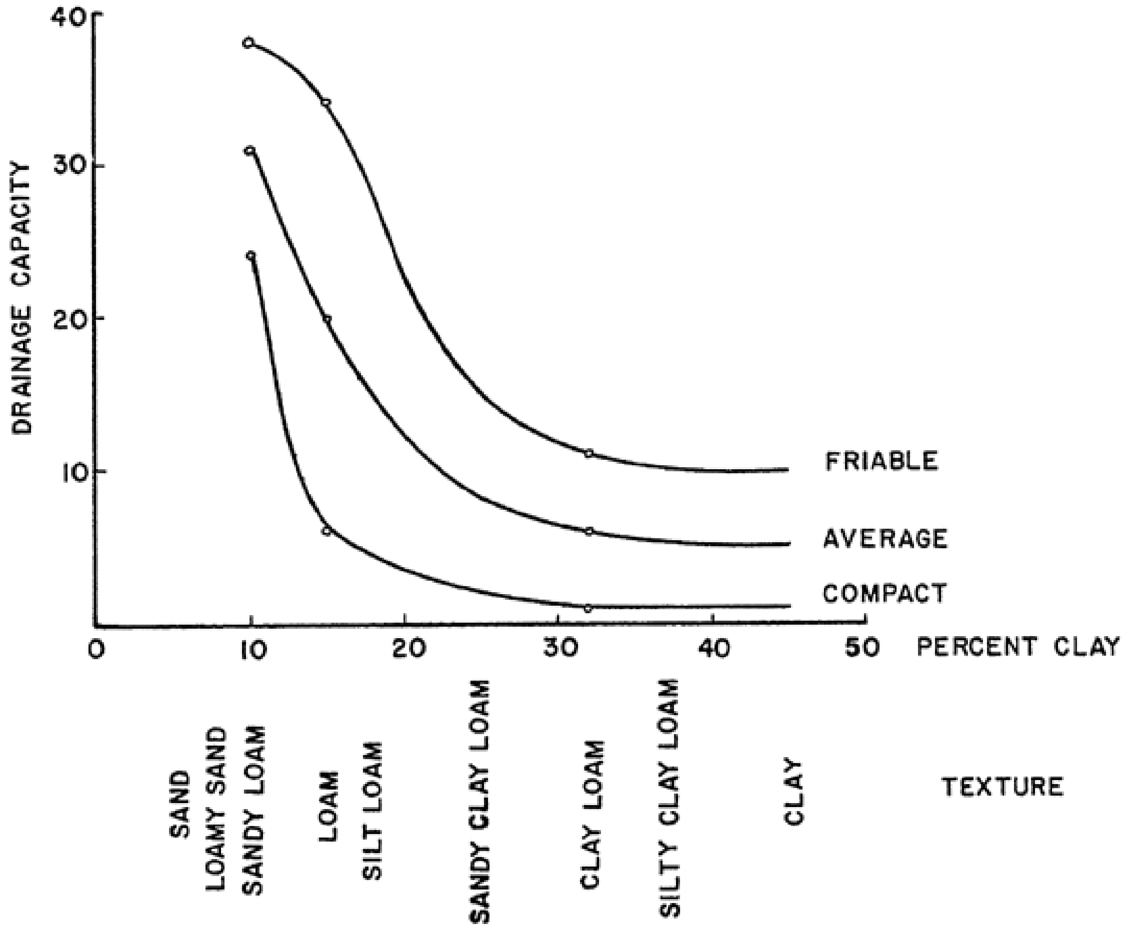

Fig. 9—Drainage capacity on texture by consistence classes. Source of data: Table 9.

To use the data in Table 9 to best advantage, they must be related to definite textural classes, rather than to broad groups. This is accomplished in Figure 9, in which drainage capacity is plotted on percent clay. Three curves are shown; the upper one represents a well-aerated, friable subsoil; the middle curve, an average (slightly compact) subsoil; and the lower, a poorly-aerated, compact subsoil.

The curves indicate that drainage capacity of the friable soils is not affected greatly until the clay content reaches approximately 15 percent; there seems to be a critical point at which drainage capacity drops off very sharply and then gradually reaches a minimum value. For the average or slightly compact subsoil, there is a steady decrease in drainage capacity with increasing clay content up to 25 percent. In the compact subsoils, drainage capacity decreases very sharply with a small increase in clay content, after which there is a gradual decrease to a minimum value. The drainage capacity values from the curves for various subsoil textures are given in Table 10. Since the lowest value for a combination of texture and consistence is 1, the whole range of values may be used as indices of consistence without further modification.

It will be noted that no values are given for sand and loamy sand; this is intentional since it was felt that these soils would rarely have a consistence in

TABLE 10 - DRAINAGE CAPACITY BY TEXTURE AND CONSISTENCE

Texture	Consistence		
	Friable	Average	Compact
Sandy loam	38	31	24
Loam	34	20	6
Silt loam	30	16	5
Sandy clay loam	15	8	2
Clay loam	11	6	1
Silty clay loam	10	5	1
Clay	10	5	1

which aeration would be a limiting factor in tree growth. Such subsoils would be rated at the maximum value.

A refinement of the method given above is possible by using a different approach to the data of Broadfoot and Burke (1958). Instead of using the average drainage capacity for textural groups, the actual drainage capacity for each soil texture can be used as the basis for deriving a rating for consistence. The mean drainage capacity for each textural class can be used for the "average" consistence while the mean plus and minus the class standard deviation can be used for the "friable" and "compact" classes, respectively.

A comparison between the values obtained by the two methods shows a maximum difference in the ratings of two units, occurring both the compact sandy loam and the average silt loam. The ratings for consistence which will be used in the statistical analyses are those derived by the first method.

Analysis of Data

The appropriate rating was given to each independent variable according to the qualitative description or the quantitative measurement obtained in the field. As an example, a sample stand selected at random from the 309 stands measured was given ratings as follows:

Stand 14, Area 3—Site Index 50	*Rating*
Topographic location—main ridge	20
Texture of B horizon—silt loam	5
Stone content of B horizon	8
Slope position—ridge	1
Texture consistence—friable silt loam	30
Total Rating	64

To test the correlation of the variables with site index, a multiple regression analysis is required, not only for the five independent variables taken together but also in various combinations of the five.

Designating the dependent variable as 00, and the independent variables as 1, 2, 3, 4, and 5, respectively, the possible regressions of the five variables are:

00—1	00—2	00—3	00—4	00—5
00—1 2	00—2 3	00—3 4	00—4 5	
00—1 2 3	00—2 3 4	00—3 4 5		
00—1 2 3 4	00—2 3 4 5			
00—1 2 3 4 5				
00—1 3	00—2 4	00—3 5		
00—1 3 4	00—2 4 5			
00—1 3 4 5				
00—1 4	00—2 5			
00—1 4 5				
00—1 5				
00—1 2 4	00—2 3 5			
00—1 2 4 5				
00—1 2 5				
00—1 2 3 5				

The three geographic areas representing different geological histories are described in the Introduction; it is desirable to keep them separate in the analysis. Only after the area analyses are completed will all stands be grouped to determine the statistical effect of the five variables on site index of shortleaf pine in Missouri.

Finally, since each of the independent variables has been rated according to its effect on soil moisture availability or on soil aeration, the sum of the ratings for each stand is an expression of the influence of the site factors on site index. This procedure involves the summation of the individual ratings for each stand and of obtaining a simple regression analysis between total rating and site index.

Machine Computation of Multiple Regression Analysis. The statistical analysis of the data was carried out by the IBM 650 installation of the computer center at Syracuse University. The computation of the 120 multiple regressions—30 for each geographic area and 30 for the combined data—plus the simple regression of total rating on site index, took a total of 9 hours and 12 minutes.

The following data are printed on the IBM 650 read-out sheets:

a. Means of the dependent and independent variables.
b. Standard deviation of the dependent and independent variables.
c. Sum of the observed values of the dependent and independent variables.
d. Correlation coefficient (r) for each independent variable with the dependent.
e. Regression coefficients (b) for the independent variables.

f. Partial correlation coefficients of each independent variable while all others are held at their mean values.
g. Unbiased standard error of the regression coefficient.
h. Correlation coefficients between independent variables; i.e., the interaction coefficients.
i. The 'a' term in the multiple regression equation
$Y = a + b_1 X_1 + \ldots . b_n X_n$.
j. The multiple correlation coefficient (R) of the independent variables taken together.

RESULTS

Estimating Site Index by Single Independent Variables

Since each of the five independent variables is associated with site index, it is of interest to examine the data to determine whether the independent variables are equally as effective in estimating site index. Not only does interest lie in the effectiveness of the five independent variables for each study area but also in the combined area which takes into account the whole of the shortleaf pine area in Missouri.

Table 11 shows the correlation coefficients, the coefficients of determination, and the standard errors of the dependent variable for each of the independent variables by study area and for the data combined. The complete statistical results are given in the Appendix as Tables 19, 20, 21, and 22.

Estimating Site Index by Means of Topographic Factors or Soil Factors.

In this study, there are two topographic factors—slope and aspect (X_1) and slope position (X_4)—which have been used to estimate site index.

In contrast to the topographic factors is the estimate of site index using soil characteristics. such as texture (X_2), stone content(X_3), and consistence (X_5). An estimate using soil factors alone involves observation and measurements taken in a soil pit and is therefore not as easily obtained as one using topographic factors.

Table 12 gives the statistical results for comparing these two groups of independent variables.

Perhaps a more realistic approach would be to compare the data for the topographic factors against *any combination of two soil factors.* The data show that each of the independent variables is positively correlated with site index; it is likely, therefore, that the multiple correlation coefficient will be of a higher value for three soil factors than for two topographic factors. Table 13 gives the results of this comparison.

Estimating Site Index Using all Five Independent Variables

As pointed out in the section above, each of the independent variables is postively correlated with site index. The numerical value of the multiple correlation coefficient will depend, to some extent, upon the individual correlation

TABLE 11 - COMPARISON BETWEEN SINGLE INDEPENDENT VARIABLES IN ESTIMATING SITE INDEX BY STUDY AREA

Independent Variable	Correlation Coefficient				Coefficient of Determination				Stand. Error of Dependent[a]			
	Area 1	Area 2	Area 3	Combined	Area 1	Area 2	Area 3	Combined	Area 1	Area 2	Area 3	Combined
Slope and Aspect (X_1)	.209*	.580**	.520**	.480**	.040	.336	.270	.230	±5.62	±5.12	±4.00	±5.44
Texture of B Hor. (X_2)	.563**	.651**	.577**	.568**	.316	.424	.333	.323	±4.75	±4.77	±3.82	±5.10
Stone Content of B (X_3)	.076	.505**	.230	.242**	.005	.255	.053	.058	±5.73	±5.43	±4.56	±6.02
Slope position (X_4)	.441**	.607**	.431**	.422**	.195	.368	.186	.178	±5.16	±5.00	±4.23	±5.62
Consistence (X_5)	.132	.669**	.354**	.388**	.017	.447	.125	.150	±5.70	±4.67	±4.38	±5.72

[a] In site index units.
* Denotes significance at the 5 percent level.
** Denotes significance at the 1 percent level.

Area 1 - Granite Hills
Area 2 - Oregon County
Area 3 - Dent County

TABLE 12 - COMPARISON BETWEEN TOPOGRAPHIC FACTORS AND SOIL FACTORS IN ESTIMATING SITE INDEX BY STUDY AREA

Study Area	Multiple Correlation Coefficient		Coefficient of Determination		Standard Error of Dependent c/	
	X_1X_4 a/	$X_2X_3X_5$ b/	X_1X_4 a/	$X_2X_3X_5$ b/	X_1X_4 a/	$X_2X_3X_5$ b/
1	.478**	.713**	.228	.508	±5.08	±4.08
2	.692**	.853**	.478	.727	±4.56	±3.31
3	.595**	.685**	.354	.468	±3.78	±3.44
Comb.	.567**	.737**	.321	.543	±5.12	±4.20

a/ X_1 - Slope and Aspect; X_4 - Slope Position.

b/ X_2 - Texture; X_3 - Stone content; X_5 - Consistence.

c/ In site index units.

** Denotes significance at the 1 percent level.

TABLE 13 - COMPARISON OF STATISTICS BETWEEN TOPOGRAPHIC FACTORS AND ANY COMBINATION OF TWO SOIL FACTORS BY STUDY AREA

	Independent Variables							
	Topographic		Soil					
	X_1X_4		X_2X_3		X_2X_5		X_3X_5	
Study area	r	r^2	r	r^2	r	r^2	r	r^2
Granite Hills (1)	.478**	.226	.564**	.318	.707**	.502	.183	.033
Oregon County (2)	.692**	.478	.704**	.493	.845**	.714	.737**	.535
Dent County (3)	.595**	.357	.586**	.345	.667**	.444	.465**	.208
Combined	.567**	.323	.571**	.326	.734**	.538	.475**	.226

** Denotes significance at the 1 percent level.

X_1 - slope and aspect.

X_2 - texture of the B horizon.

X_3 - stone content of the B horizon.

X_4 - slope position.

X_5 - consistence of the B horizon.

coefficients and on the degree of interaction between them. If interaction between any two variables is a significant value, the combined multiple correlation coefficient will be a lower value than if there were no interaction. A significant interaction between two variables indicates that the two are not independent of each other and that any simple effect is dependent upon the value of the other variable. Table 14 gives the interaction coefficients for each combination of the five independent variables for each study area and for the combined areas.

TABLE 14 - INTERACTION COEFFICIENTS BETWEEN VARIABLES FOR EACH STUDY AREA AND FOR THE COMBINED AREAS

Combination of Variables	Study Area			Combined
	1	2	3	
X_1X_2	.195	.272**	.202*	.210**
X_1X_3	-.116	.241*	.240*	.117*
X_1X_4	.055	.471**	.298**	.274**
X_1X_5	.160	.403**	.295**	.300**
X_2X_3	.189	.399**	.228*	.334**
X_2X_4	.442**	.366**	.317**	.384**
X_2X_5	-.444**	.222*	.035	-.129*
X_3X_4	.258*	.310**	.183	.275**
X_3X_5	-.332**	.339**	-.153	-.078
X_4X_5	-.121	.333**	.095	.061

* - Interaction significant at the 5 percent level.

** - Interaction significant at the 1 percent level.

Area 1 - Granite Hills.

Area 2 - Oregon County.

Area 3 - Dent County.

The data for estimating site index by use of the five independent[7] variables is given in Table 15.

Estimating Site Index by the Cumulative Total of the Independent Variables

The independent variables taken singly or in various combinations provide a measure for the estimation of site index; the precision and reliability of the

[7]In view of the interaction coefficients listed in Table 14, a better term for the variables would be "interdependent". Providing the distinction is recognized, the former term "independent" will continue to be used.

TABLE 15 - STATISTICAL DATA FOR THE ESTIMATION OF SITE INDEX USING FIVE INDEPENDENT VARIABLES BY STUDY AREA

Study Area	Multiple Correlation Coefficient	Coefficient of Determination	Standard[a] Error of Dependent
	$X_1X_2X_3X_4X_5$	$X_1X_2X_3X_4X_5$	$X_1X_2X_3X_4X_5$
1	.730**	.533	±4.02
2	.901**	.812	±2.77
3	.763**	.582	±3.08
Combined	.779**	.607	±3.91

[a]In site index units.

**Denotes significance at the 1 percent level.

estimate depend upon the value of the individual correlation coefficients or, in the case of two or more variables, the multiple correlation coefficient.

If the ratings given to each of the five independent variables were added and the total were used as an independent variable, the prediction of site index would be less complicated mathematically. There would be only one independent variable (total rating) to form a regression equation rather than five, each with its own regression coefficient.

The data using the cumulative total as a single independent variable are given in Table 16.

TABLE 16 - STATISTICAL DATA FOR THE ESTIMATION OF SITE INDEX USING THE CUMULATIVE TOTAL RATING AS A SINGLE INDEPENDENT VARIABLE, BY STUDY AREA

	1a/	2b/	3c/	Combined
$\bar{X} \pm s$	63.39±11.21	65.22±14.51	67.71±10.82	65.37±12.91
a	39.45	29.96	40.37	31.02
$b \pm s_b$	.201±.049	.358±.023	.267±.032	.362±.022
$s_{\bar{y}}$	±5.28d/	±3.46	±3.66	±5.10
r	.396**	.835**	.623**	.676**
r^2	.157	.696	.388	.457

a/ Granite Hills.

b/ Oregon County.

c/ Dent County.

d/ In site index units.

** Denotes significance at the 1 percent level.

DISCUSSION OF RESULTS

The evaluation of the five independent variables was obtained by a rational and logical approach to the effect of each variable on soil moisture availability. The framework upon which this study is built is that soil moisture is a limiting factor in the growth of shortleaf pine in Missouri. Consequently, the variables chosen to represent various facets of soil moisture availability should (1) be significantly correlated with the dependent variable which is to be estimated and (2) be able to account for a reasonable percentage of the total variance of the dependent variable.

The growth processes of a tree are very complex and it is doubtful whether all factors responsible for affecting growth could ever be measured. This being the case, investigators choose some small number of variables and study their individual or combined effects on the dependent variable in the hopes that each variable will fulfill the two conditions presented above.

Rather than offer a detailed discussion of the results, an attempt will be made to:

1. Explain non-significant correlation of independent variables where they occur.
2. Evaluate the method which has been proposed and developed as to its theoretical and practical application to site index estimates.

Before explaining non-significance of some of the independent variables, a distinction must be made at the outset between *statistical significance* and *meaningfulness* in interpreting the results. The absolute value of a statistically significant correlation decreases as sample size increases. If the percentage reduction in total variance of the dependent variable is small, i.e., 'r' is small though statistically significant, the correlation may be useless from a practical standpoint. Thus, quite a number of the correlation coefficients in the tables presented in this paper are significant at the 5 percent or the 1 percent level, yet the reduction in total variance is in the order of only 4 percent to 10 percent, because the sample size was large for each study area. The distinction is even greater for the combined area for which N = 309.

Non-significant Correlation of Independent Variables

Two criteria were offered for the selection of independent variables. If these criteria are not met, certain implications may be derived:

1. The dissociation between the independent and dependent variables is, in fact, real.
2. The evaluation of an independent variable does not reflect its true relationship to the dependent variable. In other words, the hypothesis of no correlation is accepted when it should be rejected. In statistical terms, this is classed as a Type II error.
3. Field observation and measurement of the dependent and independent variables may contain systematic as well as random errors which tend to mask the correlation between the dependent and independent variables.

4. The original frame of reference may be erroneous. In the present study, soil moisture availability is assumed to be the limiting factor in the growth of shortleaf pine in Missouri. The selection and evaluation of the independent variables were based on this premise.

The statistical significance of the correlation coefficients of some of the independent variables with the dependent, and the high percentage of total variance accounted for by individual and combinations of some independent variables, makes one believe that the original frame of reference is correct. That is, that soil moisture availability is actually a limiting factor in growth of shortleaf pine in Missouri as measured by *some* of the independent variables and by the combination of all of them.

Non-Significance of Stone Content

Table 11 shows that stone content (X_3) is not significantly correlated with site index in Study Area 1 (Granite Hills) or in Study Area 3 (Dent County), even though an investigation showed that stone content was an inverse function of moisture-holding capacity of the soil. Evidently, some error has been introduced into the conversion of stone content to soil moisture availability, or the field observation of stone content has not been inconsistent. Another possibility is that there is some feature of the two sudy areas which is not present in the third, where the correlation is significant at the 1 percent level.

The field observation of stone content was accomplished as objectively as possible but there remains some margin for error when a factor is *estimated* rather than *measured.* An estimate of stone content becomes a matter of judgement on the part of the field observer who may be biased consistently high or low. Systematic errors in field observation may be partly responsible for the lack of significant correlation, but to what extent, it is not known.

There remains the question of differences between study areas to account for the lack of correlation and to determine whether there is a special feature in one or both areas which may be responsible.

Study Area 1 (Granite Hills) is a very complex area geologically. It is felt that the lack of correlation between stone content and site index is a result of the soils found in the area. This is particularly true of the coarse, sandy soils derived from the Lamotte sandstone formation and certain phases of the Ashe series derived from granite. A coarse, sandy soil has a low moisture-holding capacity and rapid drainage; on this basis, the expected site index would be less than for the finer-textured soils. On the Lamotte soils, the stone content is low simply because the original formation from which the soil was derived, is a rather pure sandstone. Thus the rating given to such a soil on the basis of stone content would be a maximum; however, the rating of soil texture would be somewhat less than maximum. In this instance, the site index is influenced more by texture than by stone content. An examination of the original data shows that 23 of the 93 plots taken in Study Area 1 occur on the Lamotte sandy loam and on the lighter phases of the Ashe series.

In general, the plots occurring on the Hagerstown series, which is also stone-free, have site indices approximately five units higher than those on the Lamotte and Ashe series. Thus, the reason for the low correlation of stone content with site index in this area is not attributable to the basic method of evaluating stone content but to the peculiarity of some of the soils. This points to a fundamental consideration which must be taken into account in soil-site investigations. It is that the same independent variables cannot be used with equal effectiveness in areas where the soils are radically different.

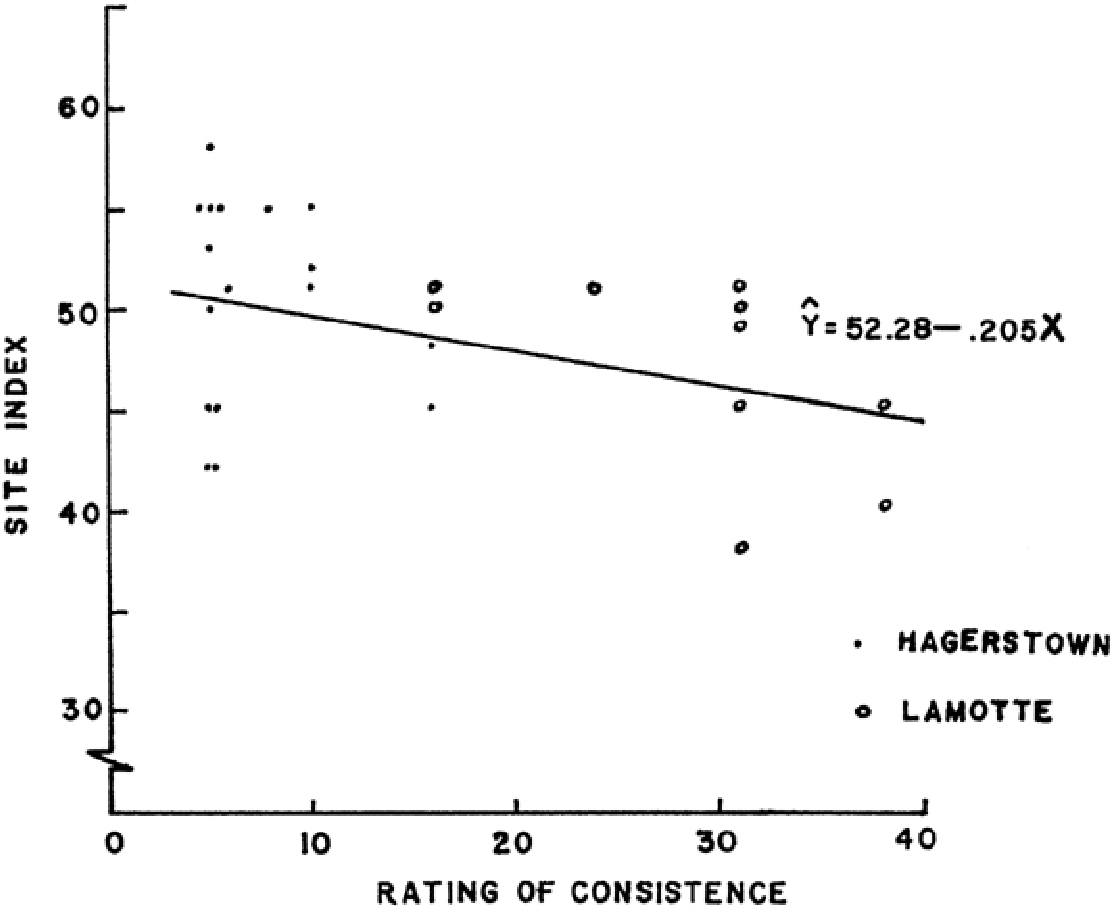

Fig. 10—Relationship between site index and consistence rating for two soils in the Granite Hills area.

Study Area 3 (Dent County) also showed a lack of significant correlation between stone content and site index. In this case, the correlation coefficient was just below that required for the 5 percent level of significance. The soil responsible for the lowering of the correlation coefficient is the Lebanon silt loam. The Lebanon soil occupies the ridges and is a loessial soil which is geologically old (Miller and Krusekopf 1919). The absence of stones results in a maximum rating for stone content, but the soil is very thin and has developed a pan layer approximately 18 inches below the surface. The growth of shortleaf pine stands on the ridges is influenced more by the shallowness of the soil than the fact that the soil is stone-free. Of the 112 plots taken in the area, 21 are situated on main or spur ridges where the soil was classified as Lebanon silt loam. The significant correlation of slope position as an independent variable in Dent County is testimony that the influence of soil depth on site index is greater than that of stone content. A solution to the determination of the real influence of stone content on site index could possibly be accomplished by calculating a separate correlation analysis of each independent variable with site index for each soil type found in the study area. This would entail a greater intensity of field sampling than was carried out in this survey.

Differences in Correlation Coefficients for Consistence by Study Area

In Study Area 1 (Granite Hills), the correlation of consistence with site index was 0.132, whereas in Study Area 2 (Oregon County) and Study Area 3 (Dent County), the correlations were 0.669 and 0.354 respectively, both of which were significant at the 1 percent level.

Is there an explainable difference between the soils in the first area and those in the other two which will account for the lack of correlation in the one and significant correlation in the other two?

One possible explanation is that there are at least six different soil types in the Granite Hills region; Krusekopf of the soil department of the University of Missouri recognizes eight soil types. Of the six which were recognized in this study, two differ markedly in their origin, texture, structure, and drainage capacities; these are the Hagerstown silty clay and the Lamotte sandy loam.

The Hagerstown soil is a stone-free, silty clay to clay soil with good moisture-holding capacity. The subsoil is generally slightly compact and drainage is considered adequate. On the basis of drainage capacity, the rating for the Hagerstown soil ranges from five to ten, with an occasional rating of 16. On the other hand, the Lamotte soil has a loose, open sandy loam subsoil in which the drainage may be classed as free. Because the consistence of the subsoil is friable to slightly compact, the rating of the Lamotte soil ranges from the maximum allowable (38) to 24.

Site indices for these two soil types do not follow the trend by the other soils in the area. The Hagerstown soil is characterized by relatively high, and the Lamotte by low site indices. When site index is plotted on consistence, the relationship appears linear with a negative slope as shown in Figure 10. This reversal of trend is partly responsible for the lack of correlation between consistence and site index when all plots in Study Area 1 are taken into account. Other factors may also be partly responsible; they are:

1. Judgement errors in the field classification of texture.
2. Inability to classify consistence classes with sufficient accuracy in the field.

These two factors may be due to lack of experience on the part of the field observer since Study Area 1 was the first area covered in this survey.

As mentioned in the discussion of stone content, where the soils are numerous and complex, a greater intensity of field sampling might reduce the error of estimate for the total sample. In addition, it would establish the relationship of consistence to site index for each soil type and show to which soil the evaluation of consistence would be applicable.

Discussion of the Method

Theoretically, the method of evaluating soil moisture availability as defined by the independent variables is sound. The statistical significance of the independent variables taken singly or in combination illustrates that soil moisture availability is correlated with site index. The exceptions to the statement have already been discussed.

The variation in the multiple correlation coefficients between study areas is caused by differences in the geological history of each area. In an area where the topography has resulted in a relatively uniform distribution of soils, such as in Oregon County, the factors chosen to represent soil moisture availability are well correlated with site index. Conversely, in areas where the distribution of soils does not follow a uniform pattern, the combined effect of the five independent variables results in a lower multiple correlation coefficient. The interaction between the independent variables (Table 14) suggests that a higher correlation could be achieved if independent variables were chosen which did not exhibit significant interaction. It would be desirable to select truly independent variables such that the effect of one variable on site index would not be modified by the value of a second variable.

Statistical significance does not always imply practical applicability. The degree of precision in estimating the dependent variable is a function of the correlation coefficient and is related to the percent of the total variance accounted for by the independent variables(s). In cases where the correlation coefficient is in the order of 0.90 or better, more than 80 percent of the total variance of the dependent variable can be accounted for. This allows a reasonable chance that the estimate of the dependent variable will be within acceptable limits of accuracy. The restriction placed on the independent variables is that they be measured with the same degree of accuracy as in the basic data which established the correlation.

Combining the evaluation of the five independent variables to estimate site index is a useful practice, although it results in a lower correlation coefficient than that obtained by measuring each independent variable separately and then combining their total effect. A comparison of the two methods is shown in Table 17.

The reason for the difference between correlation coefficients is that the cumulative total does not assign weights to each variable as the individual approach does. It does not allow for the fact that a high rating of one variable can mask a low rating in another. The cumulative total reduces the relationship with site index to a two-dimensional plane. The standard error of estimate of the dependent variable is higher for each study area when the cumulative total method is used rather than the individual method.

TABLE 17 - COMPARISON OF STATISTICS OBTAINED BY THE COMBINED EVALUATION AND INDIVIDUAL EVALUATION OF VARIABLES BY STUDY AREA

	1[a/]		2[b/]		3[c/]		Combined	
	r	r^2	r	r^2	r	r^2	r	r^2
Combined Evaluation	.396**	.157	.835**	.696	.623**	.388	.676**	.457
Individual Variables in Multiple Regression	.730**	.533	.901**	.812	.763**	.582	.779**	.607

a/ Granite Hills.

b/ Oregon County.

c/ Dent County.

** Denotes significance at the 1 percent level.

CONCLUSIONS

While it would be highly desirable to be able to predict site index with accuracy and precision by a photo-interpretation technique, it is evident from the results of this study that such a goal cannot be achieved within the areas studied. Even the addition of three soil factors does not completely resolve the problem. However, some very important and interesting observations and conclusions can be reached. They are:

1. The three areas are not parts of the same population but constitute three distinct site populations as a result of differences in geology and stand history.
2. In an area having soils which are closely related, the correlation between the independent variables, singly or combined, is not only statistically significant but meaningful.
3. Stone content and subsoil consistence are not statistically significant where one or more soils differ radically from the average soil for the area.
4. Greater sampling intensity is required in areas containing a complex of soil types in order to obtain a regression of the independent variables on site index for each soil type.
5. Estimates of site index from topographic factors alone can be useful in establishing broad site classes, but the correlation is not sufficiently high to inspire a high degree of confidence in the method.

6. The inability to obtain multiple correlation coefficients of approximately the same magnitude for the three geographic areas demonstrates that it is not always possible to fit a mathematical expression to a biological complex.
7. Where sample size is large (100 or more), the correlation coefficient need not be a large value in order to be significant. This point is often overlooked in the interpretation of statistical data.
8. The ranking of the independent variables is not the same in each study area.
9. The accuracy and precision of site index estimates using all five independent variables will vary considerably depending upon the complexity of the topographic and soil factors in the area to which they are applied.

The results indicate that the independent variables are not equally as effective in estimating site index in all three areas. Differences in soils within the Granite Hills area result in a relatively low multiple correlation (0.730); if the soil type is more uniform, such as in Oregon County, the multiple correlation coefficient is high (0.901). Individually, the independent variables showed wide variation in correlation coefficients between areas. Stone content was not significantly correlated with site index in the Granite Hills area nor in Dent County. Subsoil consistence did not have a significant correlation in Study Area 1.

Reasons for the lack of correlation were proposed; in the case of stone content, the soil types thought responsible were the Lamotte sandy loam in the Granite Hills and the Lebanon silt loam in Dent County. The Lamotte and Hagerstown soils in Study Area 1 resulted in a negative regression of site index on consistence. In all three areas, estimating site index by the two topographic factors did not result in as high a correlation coefficient with site index as that obtained by the three soil factors. All five independent variables showed a positive correlation with the dependent variable which was site index.

Summing the values for each variable and using the cumulative total as a single independent variable resulted in correlation coefficients which were statistically significant for each area and for the combined areas. The values of the correlation coeffcients were lower than those obtained by a multiple regression analysis of the five independent variables. Site index predictions using the cumulative total are not as precise as those which are predicted by the weighted value of each independent variable.

The results show, that, in general, soil moisture is a limiting factor in the growth of shortleaf pine in Missouri where site index is an expression of soil moisture availability as measured and evaluated by the two topographic and three soil factors.

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APPENDIX

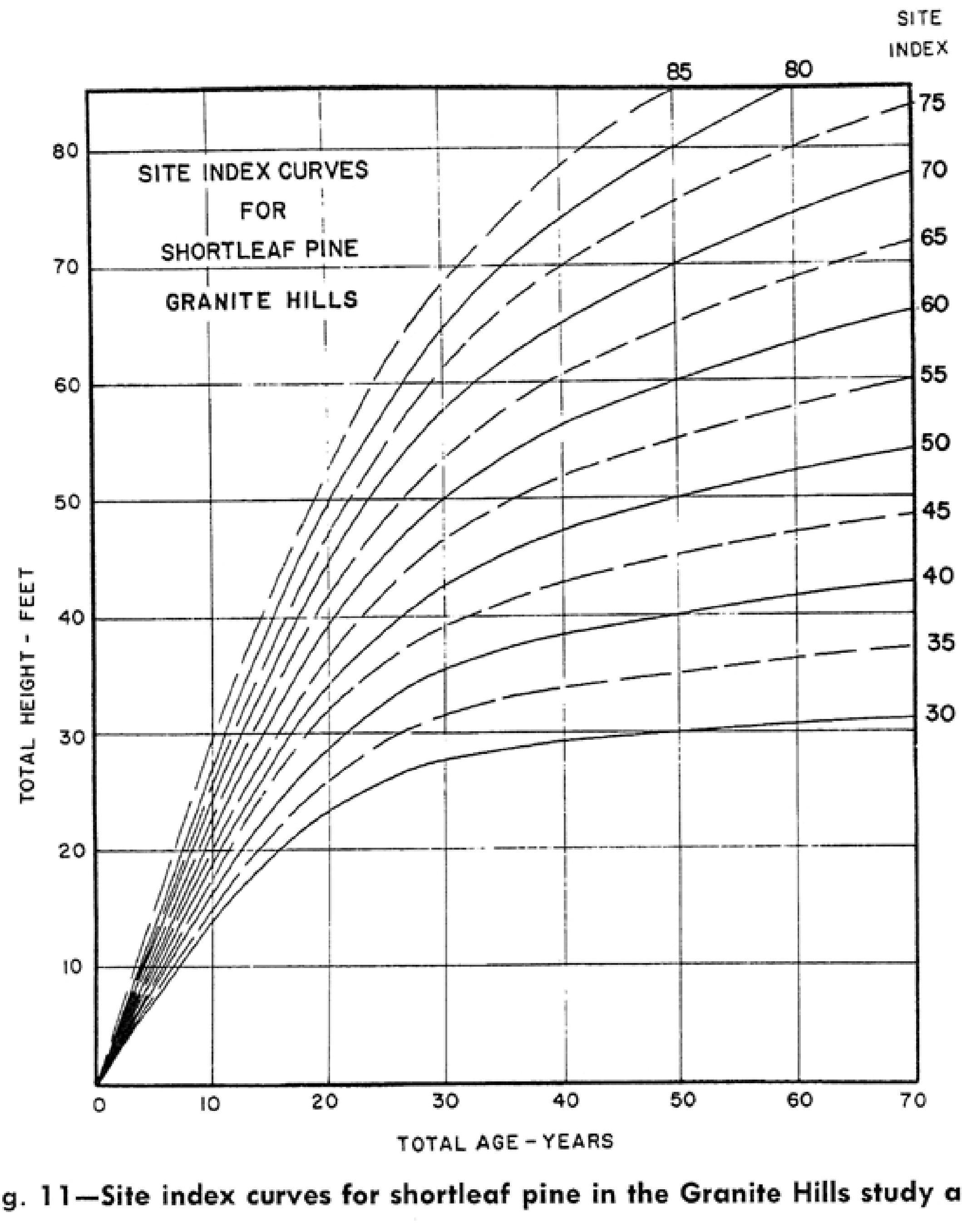

Fig. 11—Site index curves for shortleaf pine in the Granite Hills study area.

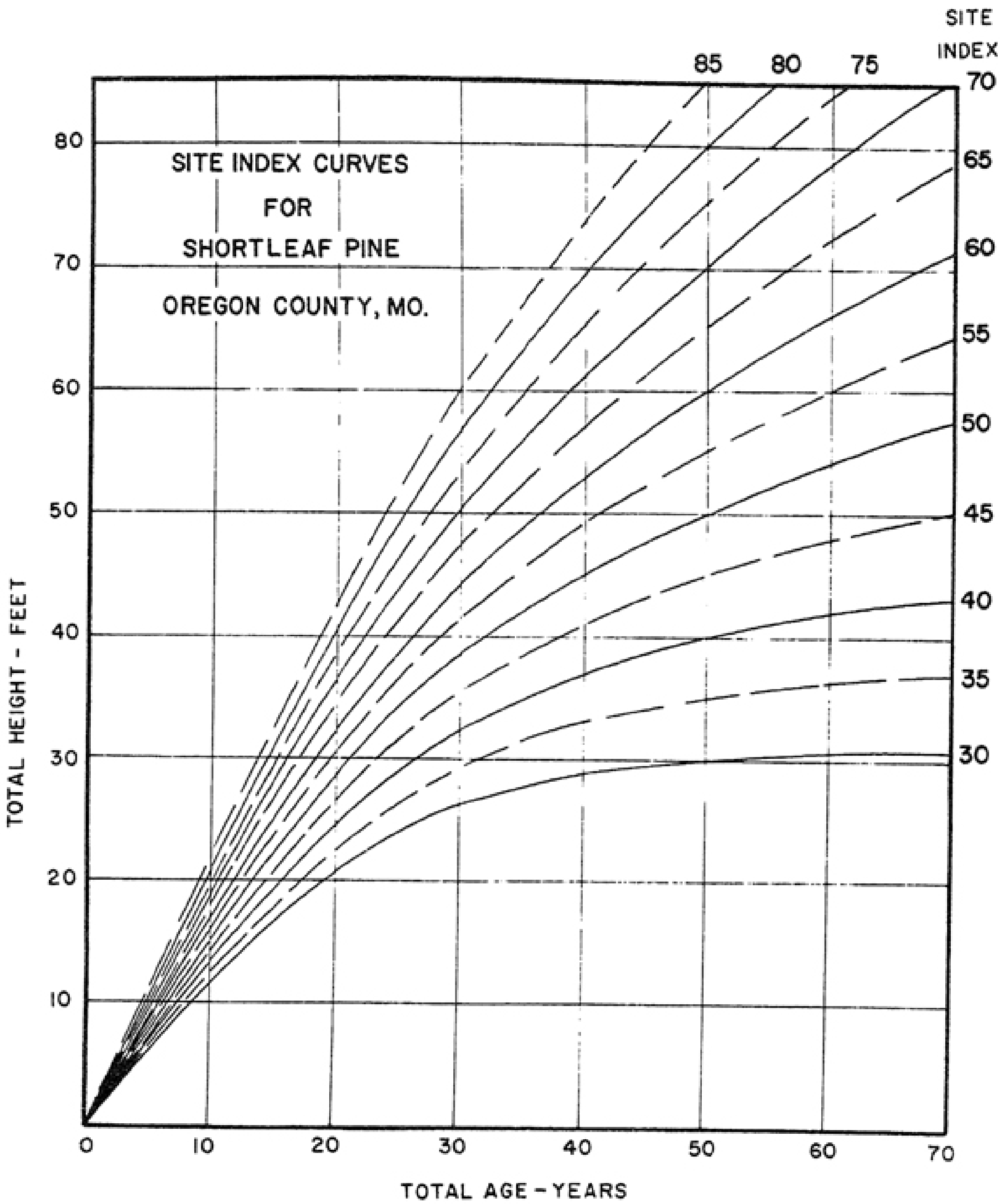

Fig. 12—Site index curves for shortleaf pine in Oregon County, Mo.

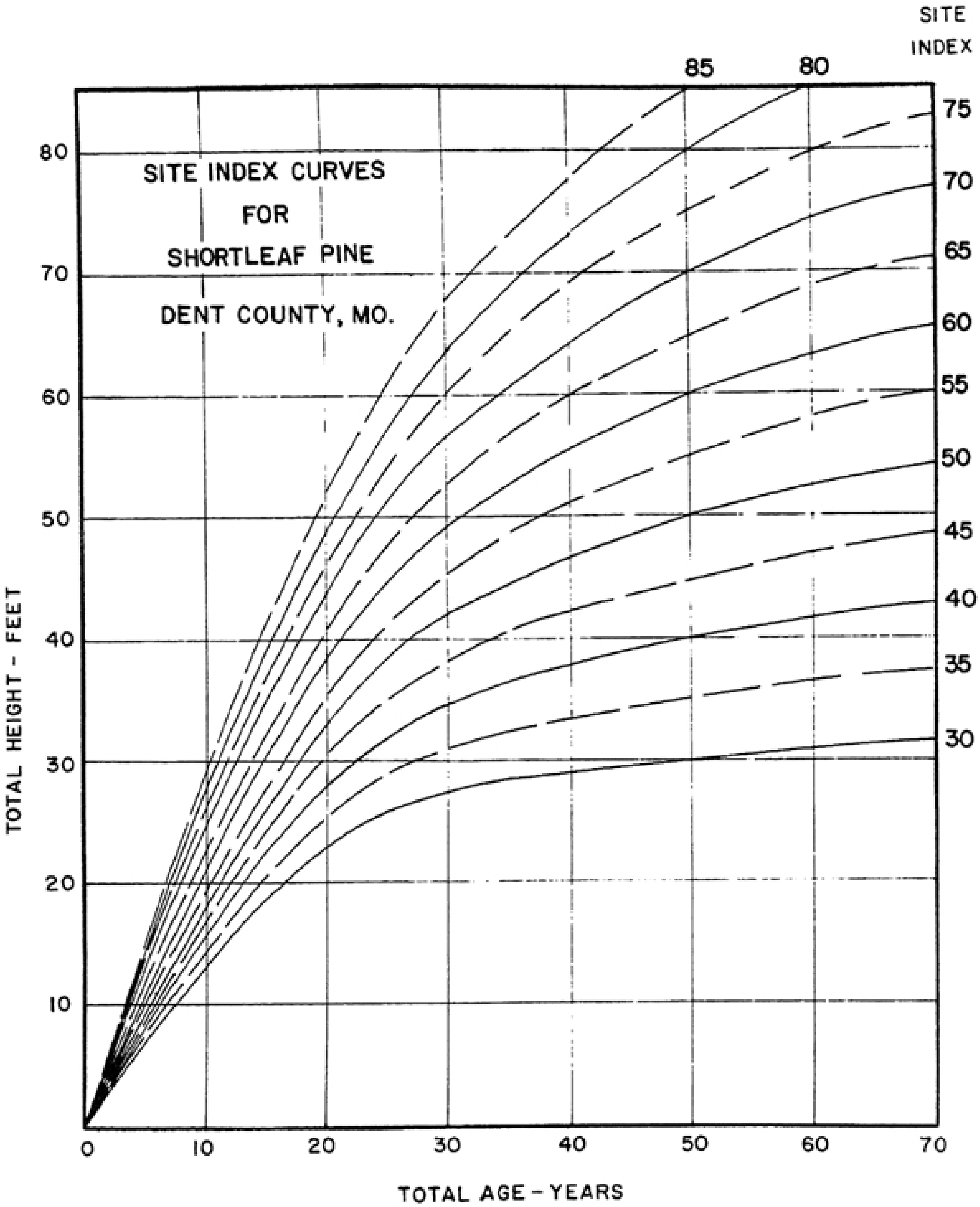

Fig. 13—Site index curves for shortleaf pine in Dent County, Mo.

TABLE 18 - CLASSIFICATION OF SOIL SERIES ON OZARK BORDER AREAS AND SOUTHEAST OZARKS

1.	Soils stone-free	
1.1	Soils derived from loess deposits, mantle thin, subsoil usually has a pan, color light gray, on broad flat ridges and plateaus.	LEBANON
2.	Soils not stone-free	
2.1	Sub soil color red or reddish brown	
2.1.1	Very few stones or chert particles	HAGERSTOWN
2.1.2	High percentage of stones or chert particles	
2.1.2.2	Sub soil color red	
2.1.2.2.1	Surface rock rusty chert	EMINENCE
2.1.2.2.2	Surface rock quartz	POTOSI
2.2	Sub soil color not red or reddish brown	
2.2.1	Northern and Eastern Ozark border areas	
2.2.1.1	Sub soil color brown	UNION
2.2.1.2	Sub soil color yellowish gray	TILSIT
2.2.2	Ozark region proper	
2.2.2.1	Soils derived from granite - numerous stones and boulders	ASHE
2.2.2.2	Soils not derived from granite	
2.2.2.2.1	Sub soil color yellow	CLARKESVILLE
2.2.2.2.2	Sub soil color brown	HANCEVILLE

TABLE 19 - STATISTICAL DATA FOR GRANITE HILLS STUDY AREA, MISSOURI

Area: Granite Hills

Independent Variables	Regression Equation	Partial correlation X_1	X_2	X_3	X_4	X_5	Multiple correlation	SE_Y
X_1	$\hat{Y} = 41.27 + .463X_1$	.209*	-	-	-	-	.209*	5.62
X_1X_2	$\hat{Y} = 36.41 + .228X_1 + 1.922X_2$	.122	.545**	-	-	-	.572**	4.74
$X_1X_2X_3$	$\hat{Y} = 36.79 + .222X_1 + 1.935X_2 - .040X_3$	.118	.538**	-.019	-	-	.573**	4.77
$X_1X_2X_3X_4$	$\hat{Y} = 37.60 + .224X_1 + 1.565X_2 - .154X_3 + .587X_4$	.123	.441**	-.075	.275*	-	.615**	4.61
$X_1X_2X_3X_4X_5$	$\hat{Y} = 31.10 - .011X_1 + 2.424X_2 + .141X_3 + .417X_4 + .240X_5$	-.007	.611**	.076	.225	.498**	.730**	4.02
X_2	$\hat{Y} = 41.36 + 1.993X_2$	-	.563**	-	-	-	.563**	4.75
X_2X_3	$\hat{Y} = 41.87 + 2.015X_2 - .079X_3$	-	.561**	-.038	-	-	.564**	4.77
$X_2X_3X_4$	$\hat{Y} = 42.72 + 1.646X_2 - .193X_3 + .586X_4$	-	.464**	-.094	.273*	-	.608**	4.62
$X_2X_3X_4X_5$	$\hat{Y} = 30.89 + 2.418X_2 + .142X_3 + .417X_4 + .240X_5$	-	.627**	.077	.226	.510**	.730**	4.00
X_3	$\hat{Y} = 50.61 + .187X_3$	-	-	.076	-	-	.076	5.73
X_3X_4	$\hat{Y} = 49.29 - .100X_3 + 1.034X_4$	-	-	-.044	.438**	-	.443**	5.18
$X_3X_4X_5$	$\hat{Y} = 45.70 + .055X_3 + 1.050X_4 + .098X_5$	-	-	.023	.451**	.205	.480**	5.10
X_4	$\hat{Y} = 48.58 + 1.009X_4$	-	-	-	.441**	-	.441**	5.16
X_4X_5	$\hat{Y} = 46.18 + 1.062X_4 + .096X_5$	-	-	-	.465**	.209*	.479**	3.08
X_5	$\hat{Y} = 50.54 + .066X_5$	-	-	-	-	.132	.132	5.70
X_1X_3	$\hat{Y} = 38.68 + .489X_1 + .250X_3$	.220*	-	.103	-	-	.232*	5.63
$X_1X_3X_4$	$\hat{Y} = 39.44 + .405X_1 - .037X_3 + .995X_4$	.202	-	-.017	.430**	-	.479**	5.11
$X_1X_3X_4X_5$	$\hat{Y} = 37.46 + .356X_1 + .092X_3 + 1.015X_4 + .087X_5$	.180	-	.040	.442**	.183	.505**	5.05
X_1X_4	$\hat{Y} = 39.08 + .410X_1 + .986X_4$	.206*	-	-	.440**	-	.478**	5.08
$X_1X_4X_5$	$\hat{Y} = 38.41 + .350X_1 + 1.034X_4 + .081X_5$	.177	-	-	.460**	.180.	.504**	5.02
X_1X_5	$\hat{Y} = 40.92 + .427X_1 + .051X_5$	.192	-	-	-	.102	.231*	5.63
$X_1X_2X_4$	$\hat{Y} = 36.14 + .245X_1 + 1.537X_2 + .556X_4$	.136	.436**	-	.266*	-	.613**	4.60
$X_1X_2X_4X_5$	$\hat{Y} = 32.58 - .020X_1 + 2.416X_2 + .448X_4 + .231X_5$	-.012	.609**	-	.247	.498**	.728**	4.01
$X_1X_2X_5$	$\hat{Y} = 32.62 - .046X_1 + 2.765X_2 + .242X_5$	-.028	.687**	-	-	.506**	.707**	4.11
X_2X_4	$\hat{Y} = 41.46 + 1.620X_2 + .547X_4$	-	.458**	-	.260	-	.603**	4.61
$X_2X_4X_5$	$\hat{Y} = 32.20 + 2.404X_2 + .450X_4 + .230X_5$	-	.625**	-	.248	.512**	.728**	3.98
$X_2X_3X_5$	$\hat{Y} = 29.57 + 2.722X_2 + .242X_3 + .254X_5$	-	.701**	.131	-	.527**	.713**	4.08
X_2X_5	$\hat{Y} = 31.74 + 2.741X_2 + .239X_5$	-	.700**	-	-	.516**	.707**	4.09
X_3X_5	$\hat{Y} = 47.39 + .322X_3 + .089X_5$	-	-	.128	-	.167	.183	5.68
$X_1X_2X_3X_5$	$\hat{Y} = 30.11 - .027X_1 + 2.737X_2 + .239X_3 + .256X_5$	-.016	.685**	.129	-	.518**	.713**	4.10

Interaction coefficients	
X_1X_2	.195
X_1X_3	-.116
X_1X_4	.055
X_1X_5	.160
X_2X_3	.189
X_2X_4	.442**
X_2X_5	-.444**
X_3X_4	.258*
X_3X_5	-.332**
X_4X_5	-.121

* denotes significance at the 5% level; ** at the 1% level.

TABLE 20 - STATISTICAL DATA FOR OREGON COUNTY, MISSOURI

Area: Oregon County

Independent Variables	Regression Equation	Partial correlation X_1	X_2	X_3	X_4	X_5	Multiple correlation	SE_Y	Interaction coefficients	
X_1	$\hat{Y} = 29.76 + .979X_1$	.580**	-	-	-	-	.580**	5.12	X_1X_2	.272**
X_1X_2	$\hat{Y} = 24.68 + .734X_1 + 2.406X_2$	.552**	.630**	-	-	-	.775**	3.99	X_1X_3	.241*
$X_1X_2X_3$	$\hat{Y} = 24.10 + .679X_1 + 2.037X_2 + .578X_3$	.540**	.561**	.325**	-	-	.801**	3.79	X_1X_4	.471**
$X_1X_2X_3X_4$	$\hat{Y} = 27.71 + .513X_1 + 1.793X_2 + .490X_3 + .754X_4$	.430**	.530**	.296*	.362**	-	.831**	3.55	X_1X_5	.403**
$X_1X_2X_3X_4X_5$	$\hat{Y} = 27.22 + .318X_1 + 1.779X_2 + .256X_3 + .609X_4 + .255X_5$	.343**	.624**	.199	.371**	.629**	.901**	2.77	X_2X_3	.399**
X_2	$\hat{Y} = 39.91 + 2.942X_2$	-	.651**	-	-	-	.651**	4.77	X_2X_4	.366**
X_2X_3	$\hat{Y} = 37.70 + 2.417X_2 + .740X_3$	-	.568**	.352**	-	-	.704**	4.48	X_2X_5	.222**
$X_2X_3X_4$	$\hat{Y} = 38.12 + 1.917X_2 + .550X_3 + 1.123X_4$	-	.518**	.300**	.494**	-	.786**	3.92	X_3X_4	.310**
$X_2X_3X_4X_5$	$\hat{Y} = 33.12 + 1.848X_2 + .262X_3 + .802X_4 + .287X_5$	-	.615**	.191	.467**	.665**	.887**	2.94	X_3X_5	.339**
X_3	$\hat{Y} = 45.35 + 1.283X_3$	-	-	.505**	-	-	.505**	5.43	X_4X_5	.333**
X_3X_4	$\hat{Y} = 43.84 + .891X_3 + 1.456X_4$	-	-	.419**	.549**	-	.692**	4.56		
$X_3X_4X_5$	$\hat{Y} = 38.49 + .582X_3 + 1.113X_4 + .295X_5$	-	-	.338**	.514**	.585**	.811**	3.71		
X_4	$\hat{Y} = 48.51 + 1.773X_4$	-	-	-	.607**	-	.607**	5.00		
X_4X_5	$\hat{Y} = 40.63 + 1.261X_4 + .334X_5$	-	-	-	.548**	.623**	.783**	3.93		
X_5	$\hat{Y} = 41.51 + .425X_5$	-	-	-	-	.669**	.669**	4.67		
X_1X_3	$\hat{Y} = 27.44 + .821X_1 + .984X_3$	.548**	-	.461**	-	-	.691**	4.56		
$X_1X_3X_4$	$\hat{Y} = 31.78 + .574X_1 + .799X_3 + 1.020X_4$	.413**	-	.412**	.414**	-	.753**	4.17		
$X_1X_3X_4X_5$	$\hat{Y} = 31.26 + .377X_1 + .562X_3 + .871X_4 + .257X_5$	.321*	-	.343**	.417**	.538**	.832**	3.53		
X_1X_4	$\hat{Y} = 34.56 + .639X_1 + 1.251X_4$	.420**	-	-	.464**	-	.692**	4.56		
$X_1X_4X_5$	$\hat{Y} = 33.02 + .393X_1 + 1.003X_4 + .293X_5$	.316**	-	-	.451**	.575**	.807**	3.74		
X_1X_5	$\hat{Y} = 29.10 + .626X_1 + .330X_5$	.457**	-	-	-	.584**	.750**	4.17		
$X_1X_2X_4$	$\hat{Y} = 28.61 + .540X_1 + 2.072X_2 + .841X_4$	.433**	.588**	-	.385**	-	.812**	3.70		
$X_1X_2X_4X_5$	$\hat{Y} = 27.63 + .320X_1 + 1.917X_2 + .643X_4 + .270X_5$	.339**	.662**	-	.385**	.653**	.897**	2.82		
$X_1X_2X_5$	$\hat{Y} = 24.62 + .450X_1 + 2.156X_2 + .289X_5$	.447**	.689**	-	-	.653**	.878**	3.04		
X_2X_4	$\hat{Y} = 39.74 + 2.239X_2 + 1.242X_4$	-	.580**	-	.521**	-	.762**	4.09		
$X_2X_4X_5$	$\hat{Y} = 33.59 + 1.989X_2 + .839X_4 + .302X_5$	-	.655**	-	.479**	.688**	.883**	2.98		
$X_2X_3X_5$	$\hat{Y} = 32.14 + 2.176X_2 + .349X_3 + .327X_5$	-	.644**	.226	-	.679**	.853**	3.31		
X_2X_5	$\hat{Y} = 32.71 + 2.387X_2 + .350X_5$	-	.693**	-	-	.709**	.845**	3.38		
X_3X_5	$\hat{Y} = 38.44 + .797X_3 + .357X_5$	-	-	.397**	-	.613**	.731**	4.31		
$X_1X_2X_3X_5$	$\hat{Y} = 24.31 + .439X_1 + 1.972X_2 + .313X_3 + .270X_5$	.447**	.643**	.226	-	.625**	.884**	2.98		

* denotes significance at the 5% level; ** at the 1% level.

TABLE 21 - STATISTICAL DATA FOR DENT COUNTY, MISSOURI

Area: Dent County

Independent Variables	Regression Equation	Partial Correlation X_1	X_2	X_3	X_4	X_5	Multiple correlation	SE_Y
X_1	$\hat{Y} = 43.09 + .617X_1$	.520**	-	-	-	-	.520**	4.00
X_1X_2	$\hat{Y} = 32.72 + .499X_1 + 2.436X_2$	.505**	.565**	-	-	-	.709**	3.31
$X_1X_2X_3$	$\hat{Y} = 32.55 + .495X_1 + 2.419X_2 + .051X_3$	.494**	.555**	.024	-	-	.710**	3.33
$X_1X_2X_3X_4$	$\hat{Y} = 34.18 + .447X_1 + 2.196X_2 + .016X_3 + .338X_4$	.456**	.516**	.007	.230	-	.728**	3.26
$X_1X_2X_3X_4X_5$	$\hat{Y} = 31.57 + .347X_1 + 2.183X_2 + .190X_3 + .321X_4 + .147X_5$	.370**	.535**	.093	.232	.332**	.763**	3.08
X_2	$\hat{Y} = 42.87 + 2.855X_2$	-	.577**	-	-	-	.577**	3.82
X_2X_3	$\hat{Y} = 41.36 + 2.738X_2 + .299X_3$	-	.554**	.123	-	-	.586**	3.81
$X_2X_3X_4$	$\hat{Y} = 42.53 + 2.356X_2 + .209X_3 + .509X_4$	-	.500**	.090	.310**	-	.638**	3.64
$X_2X_3X_4X_5$	$\hat{Y} = 36.40 + 2.289X_2 + .388X_3 + .434X_4 + .201X_5$	-	.527**	.180	.292*	.428**	.718**	3.30
X_3	$\hat{Y} = 53.71 + .665X_3$	-	-	.230	-	-	.230	4.56
X_3X_4	$\hat{Y} = 52.86 + .452X_3 + .768X_4$	-	-	.170	.406**	-	.457**	4.18
$X_3X_4X_5$	$\hat{Y} = 46.12 + .632X_3 + .681X_4 + .211X_5$	-	-	.250*	.391**	.389**	.574**	3.87
X_4	$\hat{Y} = 55.93 + .822X_4$	-	-	-	.431**	-	.431**	4.23
X_4X_5	$\hat{Y} = 51.01 + .765X_4 + .188X_5$	-	-	-	.427**	.348**	.533**	3.98
X_5	$\hat{Y} = 52.75 + .211X_5$	-	-	-	-	.354**	.354**	4.38
X_1X_3	$\hat{Y} = 41.57 + .585X_1 + .322X_3$	.492**	-	.126	-	-	.531**	3.99
$X_1X_3X_4$	$\hat{Y} = 42.90 + .492X_1 + .222X_3 + .560X_4$	.436**	-	.092	.328**	-	.599**	3.78
$X_1X_3X_4X_5$	$\hat{Y} = 40.18 + .390X_1 + .397X_3 + .542X_4 + .150X_5$	.354**	-	.165	.331**	.290*	.643**	3.64
X_1X_4	$\hat{Y} = 43.97 + .510X_1 + .578X_4$	.455**	-	-	.338**	-	.595**	3.78
$X_1X_4X_5$	$\hat{Y} = 42.36 + .435X_1 + .574X_4 + .129X_5$	.397**	-	-	.347**	.258*	.630**	3.67
X_1X_5	$\hat{Y} = 41.46 + .540X_1 + .131X_5$	.465**	-	-	-	.245*	.561**	3.89
$X_1X_2X_4$	$\hat{Y} = 34.24 + .448X_1 + 2.201X_2 + .338X_4$	.463**	.522**	-	.231	-	.728**	3.24
$X_1X_2X_4X_5$	$\hat{Y} = 32.37 + .367X_1 + 2.235X_2 + .331X_4 + .137X_5$	.397**	.548**	-	.238	.320*	.760**	3.08
$X_1X_2X_5$	$\hat{Y} = 30.86 + .416X_1 + 2.465X_2 + .139X_5$	.441**	.590**	-	-	.315**	.743**	3.16
X_2X_4	$\hat{Y} = 43.61 + 2.423X_2 + .526X_4$	-	.515**	-	.320**	-	.634**	3.64
$X_2X_4X_5$	$\hat{Y} = 38.76 + 2.415X_2 + .470X_4 + .187X_5$	-	.548**	-	.312**	.403**	.706**	3.34
$X_2X_3X_5$	$\hat{Y} = 34.98 + 2.607X_2 + .477X_3 + .215X_5$	-	.575**	.212	-	.439**	.685**	3.44
X_2X_5	$\hat{Y} = 37.78 + 2.800X_2 + .199X_5$	-	.605**	-	-	.409**	.667**	3.50
X_3X_5	$\hat{Y} = 46.00 + .842X_3 + .238X_5$	-	-	.307**	-	.405**	.456**	4.19
$X_1X_2X_3X_5$	$\hat{Y} = 29.95 + .391X_1 + 2.395X_3 + .228X_3 + .150X_5$	.408**	.574**	.109	-	.331**	.747**	3.16

Interaction coefficients	
X_1X_2	.202*
X_1X_3	.240**
X_1X_4	.298**
X_1X_5	.295**
X_2X_3	.228*
X_2X_4	.317**
X_2X_5	.035
X_3X_4	.183
X_3X_5	-.153
X_4X_5	.095

* denotes significance at the 5% level; ** at the 1% level.

TABLE 22 - STATISTICAL DATA FOR THE COMBINED AREAS IN MISSOURI

Area: Combined

Independent Variables	Regression Equation	Partial correlation X_1	X_2	X_3	X_4	X_5	Multiple correlation	SE_Y
X_1	$\hat{Y} = 34.46 + .842X_1$	.480**	-	-	-	-	.480**	5.44
X_1X_2	$\hat{Y} = 27.55 + .612X_1 + 2.194X_2$	.448**	.545**	-	-	-	.677**	4.57
$X_1X_2X_3$	$\hat{Y} = 27.16 + .658X_1 + 2.137X_2 + .109X_3$	.446**	.515**	.050	-	-	.678**	4.57
$X_1X_2X_3X_4$	$\hat{Y} = 28.74 + .604X_1 + 1.930X_2 + .041X_3 + .414X_4$	.415**	.467**	.019	.192**	-	.693**	4.49
$X_1X_2X_3X_4X_5$	$\hat{Y} = 25.70 + .381X_1 + 2.276X_2 + .113X_3 + .348X_4 + .242X_5$	.299**	.576**	.060	.185*	.494**	.779**	3.91
X_2	$\hat{Y} = 41.71 + 2.551X_2$	-	.568**	-	-	-	.568**	5.10
X_2X_3	$\hat{Y} = 41.01 + 2.462X_2 + .164X_3$	-	.533**	.068	-	-	.571**	5.10
$X_2X_3X_4$	$\hat{Y} = 41.66 + 2.114X_2 + .056X_3 + .616X_4$	-	.468**	.024	.261**	-	.610**	4.93
$X_2X_3X_4X_5$	$\hat{Y} = 32.46 + 2.441X_2 + .135X_3 + .450X_4 + .285X_5$	-	.590**	.069	.230**	.560**	.754**	4.09
X_3	$\hat{Y} = 50.08 + .670X_3$	-	-	.242**	-	-	.242**	6.02
X_3X_4	$\hat{Y} = 49.04 + .378X_3 + 1.006X_4$	-	-	.145*	.381**	-	.442**	5.57
$X_3X_4X_5$	$\hat{Y} = 42.25 + .487X_3 + .917X_4 + .240X_5$	-	-	.203**	.382**	.421**	.582**	5.06
X_4	$\hat{Y} = 51.42 + 1.104X_4$	-	-	-	.442**	-	.442**	5.62
X_4X_5	$\hat{Y} = 45.57 + 1.046X_4 + .230X_5$	-	-	-	.433**	.400**	.557**	5.16
X_5	$\hat{Y} = 48.39 + .245X_5$	-	-	-	-	.388**	.388**	5.72
X_1X_3	$\hat{Y} = 31.71 + .803X_1 + .522X_3$	.469**	-	.213**	-	-	.515**	5.32
$X_1X_3X_4$	$\hat{Y} = 33.73 + .682X_1 + .329X_3 + .740X_4$	.416**	-	.139	.307**	-	.579**	5.08
$X_1X_3X_4X_5$	$\hat{Y} = 32.10 + .521X_1 + .425X_3 + .734X_4 + .186X_5$	.334**	-	.188*	.332**	.341**	.642**	4.78
X_1X_4	$\hat{Y} = 35.58 + .691X_1 + .821X_4$	.418**	-	-	.344**	-	.567**	5.12
$X_1X_4X_5$	$\hat{Y} = 34.55 + .543X_1 + .838X_4 + .174X_5$	.342**	-	-	.367**	.319**	.625**	4.86
X_1X_5	$\hat{Y} = 33.43 + .701X_1 + .169X_5$	.414**	-	-	-	.292**	.544**	5.21
$X_1X_2X_4$	$\hat{Y} = 28.91 + .605X_1 + 1.947X_2 + .421X_4$	.415**	.483**	-	.197**	-	.693**	4.49
$X_1X_2X_4X_5$	$\hat{Y} = 26.19 + .383X_1 + 2.322X_2 + .367X_4 + .240X_5$	.300**	.594**	-	.197**	.492**	.778**	3.91
$X_1X_2X_5$	$\hat{Y} = 24.97 + 2.707X_1 + .216X_2 + .298X_5$	.332**	.646**	-	-	.492**	.768**	3.99
X_2X_4	$\hat{Y} = 41.91 + 2.138X_2 + .626X_4$	-	.485**	-	.268**	-	.610**	4.93
$X_2X_4X_5$	$\hat{Y} = 33.10 + 2.498X_2 + .473X_4 + .284X_5$	-	.610**	-	.244**	.557**	.753**	4.10
$X_2X_3X_5$	$\hat{Y} = 31.58 + 2.707X_2 + .216X_3 + .298X_5$	-	.642**	.108	-	.569**	.738**	4.20
X_2X_5	$\hat{Y} = 32.56 + 2.822X_2 + .296X_5$	-	.676**	-	-	.565**	.734**	4.22
X_3X_5	$\hat{Y} = 42.66 + .759X_3 + .259X_5$	-	-	.297**	-	.421**	.475**	5.47
$X_1X_2X_3X_5$	$\hat{Y} = 24.32 + .421X_1 + 2.457X_2 + .172X_3 + .247X_5$	.327**	.616**	.091	-	.496**	.770**	3.98

Interaction coefficients	
X_1X_2	.210**
X_1X_3	.117*
X_1X_4	.274**
X_1X_5	.300**
X_2X_3	.334**
X_2X_4	.384**
X_2X_5	-.129*
X_3X_4	.275**
X_3X_5	-.078
X_4X_5	.061

* denotes significance at the 5% level; ** at the 1% level.