SOIL-SITE EVALUATION FOR
BLACK WALNUT IN NORTHEAST KANSAS

by

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CHAPTER I

INTRODUCTION

Juglans nigra, American black walnut, is the most valuable tree species in Kansas. Kansas is one of the top states in the nation for total walnut growing stock volume and growth potential. It is the second ranking state in domestic walnut veneer log production.

Black walnut is common in the eastern one-third of the United States (Fig. 1). The range extends northward to southern Minnesota, Wisconsin, and Michigan including the southern half of New York to the Atlantic coast. It reaches southward to northern Florida and westward to eastern Texas. The Mississippi Valley and Delta regions are excluded, but it does well in the Appalachians and the Midwest.

The natural growing range of black walnut extends over most of the eastern one-third of Kansas. This area contains 85% of the 1,564,000 acres of natural woodlands in the state, and receives the most rainfall. In the western one-half, the black walnut is generally restricted to the streams, river terraces, and drainage areas where moisture is sufficient for growth (stricler 1973).

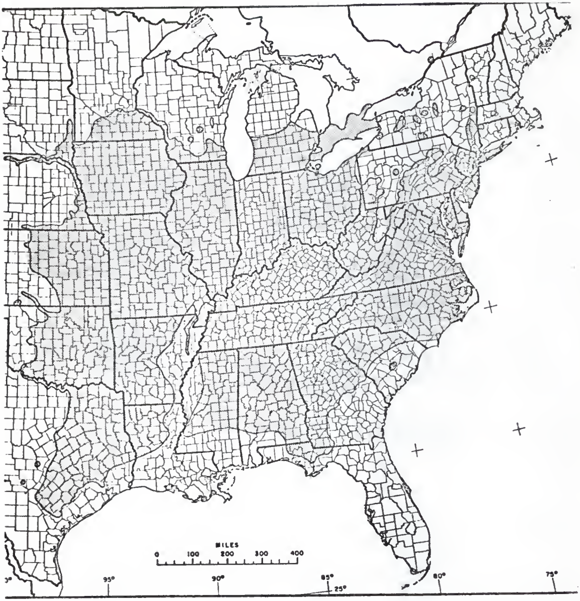

Figure 1. Natural Range of American black walnut Juglans nigra. (Reprinted from U.S.D.A. Silvics of Forest Trees in United States. Handbook No. 271.)

Principally the stands are elm-ash-cottonwood (bottomland type), which accounts for about one-half of the acreage. The upland forest type is oak-hickory and is usually younger than the other major type.

Kansas is estimated to have about 60 million cubic feet of black walnut. About 120 million board feet are sawtimber logs and 62% of these are of grades 1 and 2. Black walnut has been one of the heaviest cut species in Kansas, leaving about 40% as poletimber. Poletimber stands provide an excellent opportunity for stand improvement techniques.

Interest in planting black walnut is on the rise, since the value of the crop is increasing and establishment of successful plantations are feasible.

Site selection is an important criterion in growing black walnut. The soil has to be of good quality to yield maximum growth and quality logs. Characteristics such as drainage, sufficient fertility, thick surface horizon of silt-loam or loam, and neutral pH must be present to obtain a fast growing, high quality crop. Best sites can be found on floodplains and terraces or protected coves, but naturally, black walnut can be found on a wide variety of conditions. The poorer sites usually do not yield a high quality log. These would include upland sites with high clay content in the B horizon, and tops of ridges and slopes with shallow soils.

The average farm has many potential sites for growing black walnut that are too small to be productive for crops. These include edges of streams and small coves that could yield valuable logs, and provide other benefits to the landowner. Knowledge of the potential of these sites would be of great benefit to urge the landowner to invest his time and money into the production of black walnut.

CHAPTER II

LITERATURE REVIEW

With increasing demands for timber products, foresters are searching for ways to increase productivity. To achieve this they have a way to evaluate site quality. The direct estiamte of site index is the most widely used methods. And because it is widely used, more information has been developed for this method than for any other.

With the appropriate site index curves for a particular area, one can judge (somewhat accurately) the type of growth to expect from a particular species of tree for that type of site. An example of direct estimate site index curves is a graph showing the height-age relationship as shown in Figure 2.

After a site index graph has been constructed for an area and species, sites can be evaluated by knowing the height and age of dominant trees. The two values are found on the graph and the point of intersection lies on the value of the site index curve. Site index curves are usually based on average stand height at 50 years of age.

The main disadvantage of site index curves are that they do

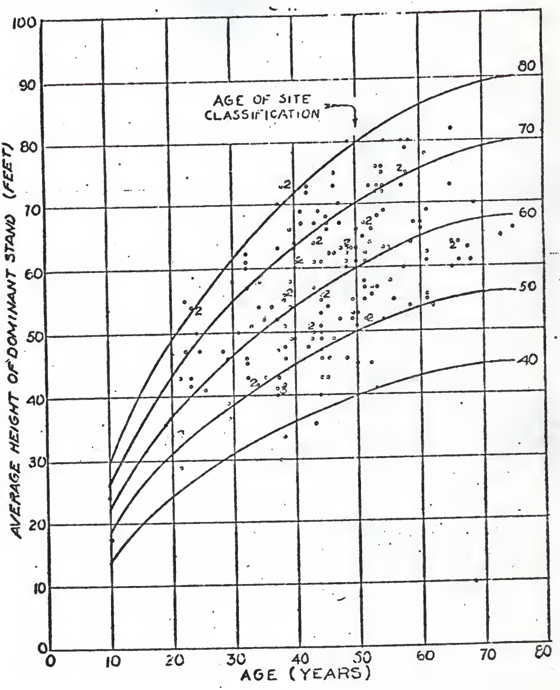

Figure 2. Site Index Curves for J. nigra by Kellogg (unpublished manuscript covered by Brinkman 1966)

not apply to all sites. Knowledge of the site index for one area may not apply to another (Jones 1969). Site index curves must be worked out for each species and area to be evaluated.

Other factors that affect direct site index estimation are these:

1) Stand density can influence tree height.

2) Most site index curves are based upon dominant-codominant trees, while curves based on dominant trees alone yield a better site index.

3) A very large sample is needed to avoid error.

4) Tree growth varies over the life span of a tree.

5) Genetically superior trees are utilized, thus not giving a true representation of stand potential.

Making a site index curve is usually time consuming and laborious. In the standard method of making site index curves, trees are bored and a ring count made to determine age. Total height of several dominant-codominant trees are plotted over average age in several stands. Site index curves are calculated from the regression of total height over age. Stem analysis, another method of direct estimation, is accomplished by felling the tree, taking a section out of the tree at fixed distances up the trunk, and graphing a series of height over age coordinates, thus producing the tree curves (the stand must be as old as the index age of 50 years) for many different sites.

An alternative approach is indirect estimation of site index, in which there are: vegetational, synecological coordinates, mensurational, and environmental classifications.

Vegetational or Plant Indicator: This consists of classifying the area by surveying the vegetation and usually recording climax vegetation. Much work has been done in this area but with little useful knowledge obtained for the forester (Jones 1969).

The Scandinavian countries worked out forest habitat as compared with climax-ground vegetation, soil profile, stand structure, and secondary succession. From growth studies, yield predictions were made (Jones 1969).

This method seemed to work well in boreal forests, but is hard to apply in an area such as the United States. The main reasons for difficulty are:

1) The geologic material, soil, and topography are sufficiently different in the U.S. that they should be used as evaluation criteria.

2) On similar type of soils, the tree growth alone can affect the under story vegetation.

3) Trees have deeper root systems and are affected by deeper soil characteristics.

4) Stand density influences the climax vegetation.

5) Key plants used in evaluation are not visible during dormant seasons.

Synecological Coordinates: Bakuzis (1959) developed a system in Minnesota using vegetation. First, plants were rated according to their needs for light, moisture, heat, and nutrients. Then the site was rated by the presence of the plants. A graph was developed from the data showing the relationship of light, moisture, heat, and nutrients to the need of the species of tree.

Mensurational Methods: Some limited success has been achieved with the volume growth of diameter, and aerial photographs. But this is used when other methods (Carmean 1975) can not be applied.

Environmental Aspect: This is subdivided into the holistic approach, using the whole environment for evaluation, or the factorial approach using one limiting factor as the key to a successful apprasrial of the site.

Soil-site evaluation is usually considered to be a factorial approach but this is true only to a certain point. The soil is a medium through which outside properties can act to affect the quality and quantity of growing space and conditions for roots. The type, structure, and properties of the soil regulate the growth, but many factors influence the soil.

Root growth is primarily determined by loil moisture and aeration which is governed by the soil texture and percent organic matter (Coile 1952). Greater depths of uniform small root distribution is achieved as the coarseness increases in the soil. In some cases stoniness will yield better growth.

Some studies of the silt-plus-clay content of the A and B horizons have shown that there is decreased growth when the silt-plus-clay increases past a certain percent (Stoeckler 1948). Plasticity has been used as an evaluation guide, with about the same success (Auten 1945b). This is not surprising since plasticity is influenced by the clay content of the soil.

Other characteristics that have shown good correlations have been internal drainage, compactness when moist, color, depth to mottles, permeability, and thickness of A horizon (Coile 1952). The texture of the soil influences these characteristics, but texture alone gives poor correlations to the site index since soils of the same textural class can have different internal drainage, aeration, consistency, and structural characteristics.

Topography has to be observed when evaluation a site because in influences moisture availability and movement (Auten 1945a). Lower sites will have greater potential for moisture than the ridge tops and sides. Slope will also affect the depth of the soil to bedrock. The sides of ridges usually contain shallow soils with greater depths at the bottom of the slope due to accumulation by erosion sediments. Depth to bedrock has a high correlation to site index (Auten 1937). Greater productivity has been found with lesser slopes and greater depth to bedrock.

Soil fertility and acidity has been found to be the least influential of the soil properties (Ralston 1964). There has been no one nutrient found to be a limiting factor. In some cases, increased productivity has been observed with potassium, sodium, and nitrogen. But usually there is little correlation between fertility and site index.

Many biological factors that affect tree growth have to be included with other errors in evaluation (Carmean 1975). These may be improper stand density, competing vegetation, genetic variations, insects, and diseases. Improper stand density is probably the most limiting factor, with weeds and undesirable species robbing nutrients and, less importantly, water.

Soil-site evaluation methods have yielded high correlations with the site index. Soil characteristics that limit soil moisture and aeration correlate the best. The amount of clay in a soil is in every case a useful evaluation factor. Percent clay will influence the plasticity, cohesion, porosity, infiltration, permeability, and storage capacity of the soil.

In Kansas, most of the rain comes during the early part of the growing season, with little stored soil water accumulated throughout the winter. Even though water comes when the plant needs it the most, there is not enough water for wasting to occur and, therefore, good infiltration and storage of the water is critical for good growth.

Depth to a restricting layer such as a claypan or fragipan or a dense heavy layer governs the effective thickness of the soil (Ralston 1964). As the soil becomes shallower, the yield decreases. Recording the depth and strength of this layer could easily be done in the field and would provide useful information.

Baker and Broadfoot (1976) developed an extensive soil-site method for cottonwood applicable throughout the lower Mississippi River Valley. They evaluated physical condition, available moisture, nutrient availability, and aeration of the soil. A percentage was given to what each contributed to the maxumum growth at the age of 30. These four major factors were broken down into minor factors categorized by their level of contribution to the major factor. To evaluate a site, the factors were measured and the percentage of maximum growth was determined.

The study reported in this thesis is concerned with the soil-site approach. Consideration will be given to the total environment to classify the material that is collected for the soil characteristics.

CHAPTER III

OBJECTIVES OF THE STUDY

The objective of this study was to find the physical soil characteristics and topographic variables that affect black walnut tree growth in northeast Kansas. The usefulness of these variables will be evaluated by devising an acceptable mathematical expression to find a predicted site index for the study area. This predicted site index will be compared to the observed site index obtained from the conventional height-over-age site index curves from Kellogg.

Variables that are easy to measure and do not require highly trained personal to interpret them will be given special consideration. A method that could reasonably estimate the site index of a site with no trees present, and be used in the field by non-specialized personnel would be of great value to the field forester and potential tree farmer.

CHAPTER IV

METHODS OF INVESTIGATION

Location and Description of Sites

All sites were in the northeastern corner of the state of Kansas. Counties included were Pottawatomie, Riley, Geary, Marshall, Nemaha, Shawnee, Jefferson, Douglas, and Wyandotte (Fig. 3).

Sites were selected and marked by W. A. Geyer (Personal communication) in the computation of his direct estimate site index curves for eastern Kansas. The sites were selected for their presence of black walnut growing in a natural stand. At each site dominant trees were bored with an increment bore at stump height (about 1/2 ft) to determine their age. These trees were selected to avoid open grown trees, trees with broken tops, or trees that had been suppressed by other trees. They were then marked with tree paint and numbered for later identification. Total height of each tree was then recorded for determination of site index of the site using Kellogg's site index curves for black walnut in the Midwest (Fig. 2).

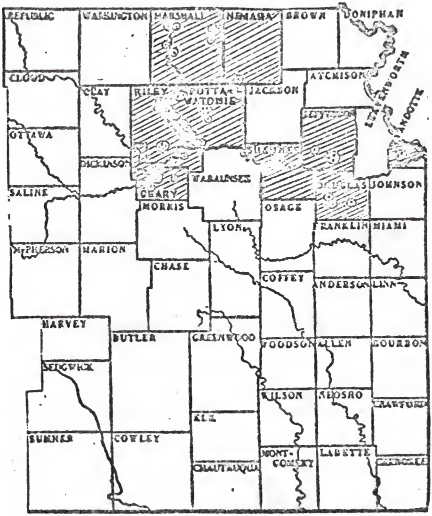

Figure 3. Northeast Kansas showing counties used and location of plots.

Of the sites that were marked, 48 were selected for the soil-site study. A base age of 50 years is the ideal age for trees because that is the base age for the Kellogg site index curves, but we used trees from age 11 to 111 due to time and location of plots. The sites were selected to cover a range of site index values. Values from 41 to 82 were included (Table I).

Field Observations

Each site was visited and the soil profile was exposed. A pit was dug, 12' or so from the walnut trees, to a depth of 3 to 5' depending on natural barriers such as rock. If a natural exposure was present it was utilized.

The horizons were then identified to a depth of 5' by the standards given in the Soil Survey Manual (1951 U.S.D.A. Handbook No. 18). If horizons were not present, intervals of 1' were used. Thickness of each horizon was measured to the nearest inch. Texture, structure, boundary, thickness, and rock content for each horizon or 1' interval was recorded (see Fig. 4 for form).

The texture was determined by the "Feel Method" and later by laboratory techniques (Foth et al 1976). The structure and boundary were classed according to standards in the Soil Survey Manual. Rock content was visually observed and given a percentage for each horizon.

The depth of the restricting layer was then determined by measuring how deeply the small roots of the trees penetrated, and

Table I. Site Indexes and Tree Ages for 48 sites.

County	Stop No.	Site Index (Kellogg)	Avg. Tree Age
Pottawatomie	2	67	21
"	5	59	48
"	6	52	36
"	7	65	40
"	8	51	34
"	9	61	32
"	10	49	63
"	12	45	60
"	13	61	90
"	15(1)	48	51
"	15(2)	48	51
"	16	40	37
"	17	60	39
"	18	58	37
"	19	63	26
"	20	48	19
"	21	49	47
"	22	70	60
Riley	1	49	48
"	3	61	29
"	4	62	29

Riley	5	70	26
"	6	67	27
"	7	65	101
"	8	70	46
Geary	1	43	53
"	3	41	62
"	4	54	53
"	5	63	110
"	7	48	11
Marshall	2	58	58
"	3	75	49
"	4	50	42
"	6	59	62
"	7	82	57
"	8	80	40
"	9	62	98
Nemaha	1	62	46
Shawnee	1	75	59
Jefferson	1	79	20
"	5,6	60	78
"	7	47	32
"	8	60	27
Douglas	8	82	34
"	9	58	54
"	11	67	86

Wyandotte	3	67	86
"	4	65	111

LOCATION ____________________ DATE ____________________

STOP NO. ____________________

No.	Horizon	pH	Depth	Thickness	Boundary	Texture Field	Texture Lab	Structure	Rock

Obs. root penetration ____________________

____

Depth of profile __________ Impermable layer __________ B.D. __________

A Horizon B.D. ______ %O.M. __________ Depth to mottles __________

Source of soil ____________________

Topography

Figure 4. Field observation sheet.

testing the strength of each layer by the penetration of a knife blade. The restricting layer was often indicated by resistance to shovel penetration while digging the pit. If there was no restricting layer or the small roots were throughout the profile, the depth was recorded as 5'.

The source of the soil parent material was recorded and a visual description of the topography was made.

Samples of every horizon or foot interval were collected and labeled for laboratory analysis. A 1qt. plastic freezer bag was filled with soil for every sample. Naturally occurring clods were then taken for bulk density analysis for the A horizon and the restricting layer, if present. Clods of about 30 gr each were stored in plastic bags for transportation and to prevent drying.

The pit was then closed and restored to as natural a condition as possible.

Laboratory Procedures

Bulk density was determined by the paraffin-clod technique (Blake 1965). A naturally occurring clod of about 30 gr was brushed to remove any loose material and examined for holes, roots, or stones. If any were found the clod was discarded. A thread was tied around the clod and the clod was weighed.

Paraffin in a beaker was heated in a water bath to about 59°C., enough to just melt the paraffin. The clod was dipped momentarily in the paraffin several times. The coating was checked for holes and air bubbles. Bubbles were broken and the clod redipped if necewsary. The clod was then weighed with the paraffin coating and then suspended from the balance and weighed in water. The water content was determined by oven drying a separate sample from the same horizon. The bulk density was then calculated as shown in Appendix A.

The texture of each sample was determined by the Bouyoucos Hydrometer procedure (Foth et al 1976). In this procedure a 50 gr sample of soil (100 gr for coarse textures) was placed in a Soil-Test baffled stirring cup. The cup was half filled with distilled water, 5 ml of 1 N sodium hexametaphosphate was added, and placed on a mixer for about 5 min or until all the aggregates were broken down.

The contents of the cup were quantitatively transferred into a Soil-Test special hydrometer jar and was filled with distilled water to the lower mark of 1130 ml (if 100 gr was used, it was filled to the upper mark of 1205 ml). The suspension was shaken horizontally to avoid creating circular currents. It was left undisturbed for 20 sec, the ASTM Soil Committee hydrometer was inserted, and at 40 sec the first reading was made. The suspension was then left for 2 hrs and the second reading made. The temperature was recorded before the first reading and after the second. A correction factor of 0.2 was added to the hydrometer reading for every degree above or below 67° F. for each reading.

The amount of sand was determined by subtracting the first corrected reading from the original 50 gr sample (the hydrometer reads grams of soil in suspension). The % sand was obtained by multiplying the amount by 2. The second corrected reading multiplied by 2 yielded the % clay. Percent silt is the percentage remaining from 100%. Sample calculations are in Appendix B.

The pH of every sample was determined by using a Coleman Portable pH meter. A 2 to 1 mixture of soil and distilled water was placed in a paper cup, stirred every 5 min for a total of 30 min. The pH was then immediately read after the last stirring. The value was rounded to the nearest tenth of a pH unit.

Statistical Analysis

The correlation between the single variables and the site index was made by graphing the variables against the site index. This was done for the variables determined in the field.

Multiple regression using the SAS 76(5) program by Barr, Goodnight, Sall, and Helwig (1976) was used for 3 approaches. First, all the quantitive variables were entered into the computer and several multiple regressions were run to obtain the best fit of the variables to site index. Stepwise and backwards regressions were used to find the best variables.

The qualitative variables, SSOIL, TOP, nad SURVEG, could not be used in the regression model. They were later used as a means for sorting the sites with the best fitting variables to obtain a final prediction equation.

Second, the sites were separated by SSOIL and a regression was run to obtain the best variables for each (categories 3 (loess) and 4 (glacial) were entered as 2 (colluvium-residuum) for this procedure). The best variables were used with the SSOIL to obtain a prediction equation for each source.

Third, the easy to measure variables were picked and, through trial and error testing, the best prediction equation was formed. The following are the variable names generated for the SAS computer runs.

Description of Variables Tested

DRL- Depth to restricting layer in inches was taken in the field; the procedure was described under field observations.

BDRL- Bulk density of the restricting layer was determined in the lab for 2 samples. The value tested was the average of the 2 samples.

TA- Thickness of the A horizon was determined in the field to the nearest inch. This was the thickness of all A horizons excluding and A3 horizons (these were considered to be zones of transition).

BDA- Bulk density of the A1 horizon was determined by laboratory procedures for 2 samples. Value used was an average of the 2 samples.

SSOIL- Source of soil was the classification of the soil at the site as 1 of 4 types as listed in Table II.

TOP- Topography was placed in one of the categories listed in

Table II. Categories used in qualitative variables.

SOURCE OF SOIL

1 alluvium

2 colluvium-residiuum

3 loess

4 glacial

TOPOGRAPHY

1 unproductive dry

2 gentle-rolling terrain (upland)

3 upper 1/3, top of slope, or ridge

4 intermittent stream and upland cove

5 flat 1st terrace (alluvial bottoms)

6 unproductive wet

7 stripmine

8 middle 1/3 slope

9 lower 1/3 slope

Table II using the description of the site in the field notes.

PCSLOPE- Percent slope was determined in the field by the Blume-Leiss Altimeter.

SURVEG- Surface vegetation was one of two categories; 1=Duff composed of forest litter and grown vegetation, and 2=Grass with grass predominantly covering the ground.

ESD- Effective soil depth (Steinbrenner 1965) was calculated for each profile, effective depth being the depth of soil minus rock content. First, the thickness of each horizon or 1 ft. increment was multiplied by the percent rock of that horizon. Then the inches of rock was subtracted from the thickness of that horizon or 1 ft. increment. The effective soil depth was the total of new values of thickness for each horizon or 1 ft. increment for the total 5' profile.

Ex. A1 horizon with 60% rock content 8" thick

$8 \times .60 = 4.8 \quad 8 - 4.8 = 3.2$ in. for ESD

ESDRL- Effective soil depth to restricting layer was computed to the depth of the restricting layer if less than 5'.

WHCP- Available water-holding capacity (AWC) was given in inches of water per inch of soil for every profile. This was accomplished by building a chart (Fig. 5) to estimate the AWC for each textural class. This chart is a combination of charts by O.W. Bidwell (1977), Salter and Williams (1965), and Franzmeirer, Whiteside, and Erickson (1960).

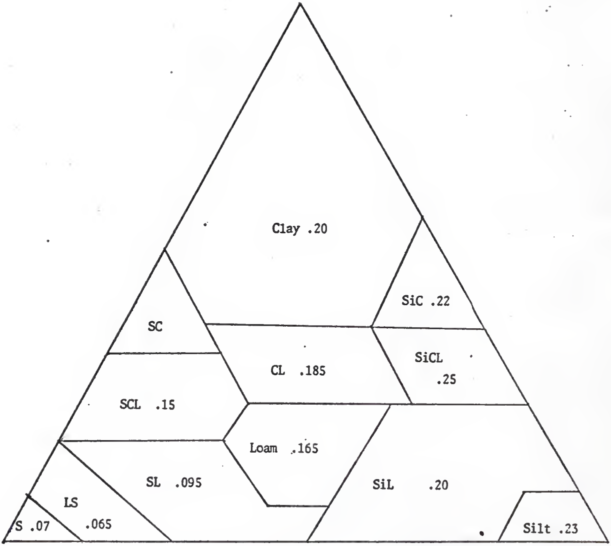

Figure 5. Textural triangle with estimated available water holding capacity in inches of water per inch of soil. Adapted from Bidwell (1977), Salter and Williams (1965), and Franzmeirer, Whiteside, and Erickson (1960).

None of these charts had specific values for each textural class. So a complete chart was made using Franzmeirer, Whiteside, and Erickson values in Michigan (they seemed the most precise) filled in by values contained in the other charts. Values not listed in the 3 charts were estimated by studying the trends of all 3 charts.

The AWC value for each horizon or 1 ft increment was determined by multiplying the new thickness value for each horizon or 1 ft increment by the value given in the chart for the texture of that horizon or 1 ft increment. The WHCP is the total of the AWC values of all horizons or 1 ft increments in the profile.

WHCRL- The same procedure as in WHCP was followed but the total was stopped at the depth of the restricting layer if less than 5'.

PHA1- This was the pH value to the nearest tenth pH unit for the top A horizon in the profile.

PHB2- This was the pH value to the nearest tenth pH unit for the B2 horizon. If the horizon was subdivided into a B21 and B22, the value for the B22 was used.

PHC- This was the pH value to the nearest tenth pH unit for the C horizon in the profile.

LOWPH- The lowest pH value in each profile.

HIGHPH- The highest pH value in each profile.

SCB2- The % silt and % clay were added together for the B2 or B22 horizon in each profile.

SCA1- The % silt and % clay were added together for the top A horizon in each profile.

PCCB2- Percent clay of the B2 or B22 horizon in each profile.

RATIO- This is the SCB2 value for 1 profile divided by the TA value for that profile.

PCCA1- Percent clay of the top A horizon in each profile.

ASP- The aspect for each site was given as a 0-360° compass reading. This is the angle in a clockwise direction that the slope faced from north. For level ground the value was 0.

CHAPTER V

RESULTS AND DISCUSSION

The strongest correlation between a single variable and site index was the thickness of the A horizon (Fig. 6). The correlation between the other single variables and site index was low. This was determined by graphing the variables against site index.

The backwards elimination procedure proved to be the most useful. It started with all the variables entered and used them to predict site index; it then proceeded to eliminate them one by one by removing the least significant variable with the highest PROB>F (which stands for the lowest alpha level) and re-evaluating the remaining variables. This procedure kept eliminating variables until all that remained were significant at the 5% level. The best fitting variables were determined by myself by selecting the group with the highest R-square and the lowest mean square which is the sum of the difference between the observed values and the predicted values all squared.

The stepwise procedure started with no variables. It then added the most significant variable with the lowest PROB>F and determined the R-square for that one variable. It then looked for the next variable that would be significant given the firstvariable. If a

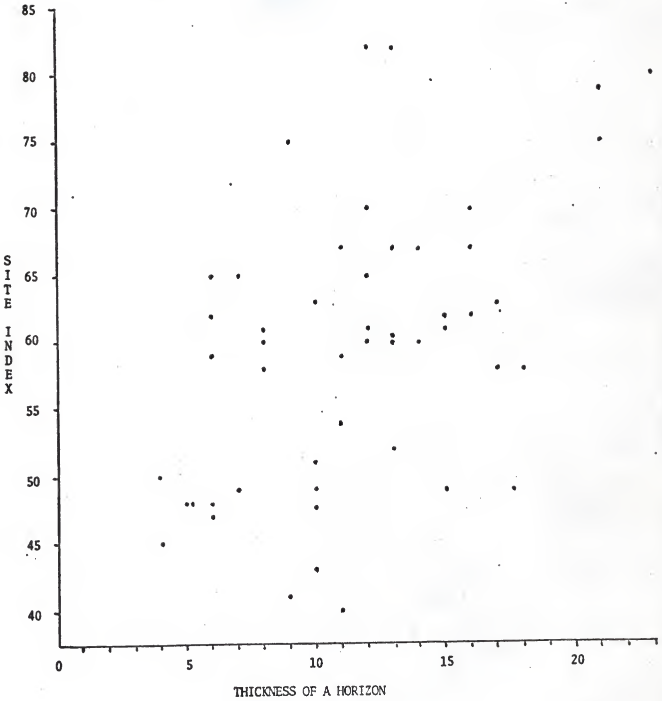

Figure 6. Graph of the best correlated variable.

variable was entered and found not to be significant by 5% given the previous variables, it was removed. The stepwise regression proved to be ineffective because it worked with such a low R-square (since one variable explained such a low percent of the model statement).

The variable, bulk density of the restricting layer (BDRL), had to be omitted since not all profiles contained a restricting layer and because the PROB>F was high. The stepwise and backward regression were run with this variable entered, but 14 cards were thrown out due to no value.

With the best variables obtained (Table III) the qualitative variables were entered in as classes to the model statement. The print out contained the predicted values for every site and the 90% confidence limits for each. Four data cards were eliminated from the deck for they contained some error to make the residual deviate more than twice the standard deviation.

Two were for trees at the extreme age limits for acceptability, one at 111 years and the other at 11. At these ages the possibility for the site index curves to be inaccurate are greater than if the tree was close to the base age of 50. The other two cards were for sites that had very high site index values. At the higher values on the end of the curve, an error in sampling would influence the prediction equation to deviate the curve more to compensate for the error than if it was located along the middle of the curve.

With the removal of the four cards the stepwise and backward

TABLE III

BEST BACKWARDS REGRESSION WITH ALL SITES INCLUDED

PHB2 REMOVED R SQUARE = 0.64195985

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	9	3438.53755612	382.05972846	7.57	0.0001
ERROR	38	1917.77494388	50.46776168		
TOTAL	47	5356.31250000			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	74.35108653				
TA	0.87760140	0.28149256	490.54042930	9.72	0.0035
ESD	0.32877080	0.15406361	229.82664113	4.55	0.0394
WHCRL	2.99671825	1.06590721	398.90278581	7.90	0.0078
WHCP	-1.55897911	0.58546422	357.84414654	7.09	0.0113
PHA1	9.60554797	4.23509635	259.61617294	5.14	0.0291
PHC	5.71939000	2.58545306	246.96769745	4.89	0.0330
HIGHPH	-16.55942232	5.09708892	532.67214693	10.55	0.0024
PCCB2	-0.39340709	0.18944491	217.63689278	4.31	0.0446
ESDRL	-0.53750006	0.26337777	210.19038096	4.16	0.0483

TABLE IV

BEST BACKWARDS REGRESSION FOUR SITES REMOVED

RATIO REMOVED　　R SQUARE = 0.80203323

	DF	SUM OF SQUARES	MEAN SQUARE	F	PROB>F
REGRESSION	11	3338.49977539	303.49997958	11.79	0.0001
ERROR	32	824.04567915	25.75142747		
TOTAL	43	4162.54545455			

	B VALUE	STD ERROR	TYPE II SS	F	PROB>F
INTERCEPT	25.92698281				
TA	1.28861825	0.21335833	939.35699780	36.48	0.0001
BDA	15.25913919	8.88341370	75.98040472	2.95	0.0955
ESD	0.48942011	0.11296849	483.33724630	18.77	0.0001
WHCRL	3.45159541	0.84058487	434.18811980	16.86	0.0003
WHCP	-2.08833046	0.42781442	613.60504306	23.83	0.0001
PHA1	12.76153007	3.12968311	428.15998159	16.63	0.0003
PHB2	-3.11899294	1.93146843	67.15136751	2.61	0.1162
PHC	7.19203089	2.07868644	308.26657175	11.97	0.0016
HIGHPH	-14.24253997	3.89755083	343.86868481	13.35	0.0009
PCCB2	-0.57057268	0.14396661	404.48246302	15.71	0.0004
ESDRL	-0.86074846	0.21265835	421.88001180	16.38	0.0003

multiple regressions were rerun. The same set of variables in the previous analysis plus 2 more (BDA nad PHB2) came out to be more significant. The mean square for error dropped from 50.46 to 25.71 and the R-square increased from .64 to .80 (comparison of Table III to Table IV). Eleven variables out of the 20 tested were used in this procedure.

With the 11 quantitative variables, the qualitative variables were examined. This was done by trial and error. All possible combinations of the three variables were run through using them to sort the quantitative variables. If the PROB>F was large, this indicated that the variable was not needed given the other variables.

The final regression is shown in Table V; topography was the only qualitative variable needed, the other variables came from the best backward regression. The R-square of .88 explains that 88% of the variation in site index is explained by the model.

The prediction equation can be obtained from Table VI. The topography of each site must be rated into one of the categories. The equation follows:

SI= Intercept (11.77916362) + TOP (times the value given for particular catagory) + TA (1.47156889) + BDA (12.26464736) + ESD (0.47027600) + WHCRL (4.19399357) + WHCP (-2.35752520) + PHA1 (10.52300802) + PHB2 (-3. 23247513) + PHC (6.82039023) + HIGHPH (-9.88148137) + PCCB2 (-0.48367093) + ESDRL (-1.00747451)

This equation had a 90% confidence interval of about 17 units

TABLE V REGRESSION MODEL FOR ALL SITES

DEPENDENT VARIABLE: SI

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
MODEL	16	3682.72592401	230.17037025
ERROR	27	479.81953053	17.77109372
CORRECTED TOTAL	43	4162.54545455	

F VALUE	PR > F	R-SQUARE	C.V.
12.95	0.0001	0.884729	7.1671
	STD DEV		SI MEAN
	4.21557751		58.81818182

SOURCE	DF	TYPE IV SS	F VALUE	PR > F
TOP	5	344.22614862	3.87	0.0089
TA	1	1150.24413074	64.73	0.0001
BDA	1	46.51094890	2.62	0.1170
ESD	1	429.16740871	24.15	0.0001
WHCRL	1	572.71029161	32.23	0.0001
WHCP	1	654.36874763	36.82	0.0001
PHA1	1	234.18720458	13.18	0.0012
PHB2	1	49.69774329	2.80	0.1060
PHC	1	190.33616884	10.71	0.0029
HIGHPH	1	129.47336823	7.29	0.0118
PCCB2	1	244.40686791	13.75	0.0010
ESDRL	1	512.60659347	28.84	0.0001

TABLE VI

PREDICTION EQUATION FOR ALL SITES

PARAMETER		ESTIMATE		T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT		11.77916362	B	0.53	0.6004	22.22362549
TOP	2	12.27677931	B	3.50	0.0016	3.50758832
	3	0.18724057	B	0.06	0.9530	3.14312934
	4	8.10114227	B	3.10	0.0045	2.61609116
	5	4.01507279	B	1.43	0.1649	2.31237720
	8	3.00497877	B	0.78	0.4422	3.85283698
	9	0.00000000	B	.	.	.
TA		1.47156889		8.05	0.0001	0.18291220
BDA		12.26464736		1.62	0.1170	7.57300376
ESD		0.47027600		4.91	0.0001	0.09569661
WHCRL		4.19399357		5.68	0.0001	0.73878377
WHCP		-2.35752520		-6.07	0.0001	0.38850995
PHA1		10.52300802		3.63	0.0012	2.89878095
PHB2		-3.23247513		-1.67	0.1060	1.93296476
PHC		6.82039023		3.27	0.0029	2.08403793
HIGHPH		-9.88148137		-2.70	0.0118	3.66090832
PCCB2		-0.48367093		-3.71	0.0010	0.13042185
ESDRL		-1.00747451		-5.37	0.0001	0.18758541

TABLE VII

PREDICTED VS. OBSERVED FOR ALL SITES

OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 90% CL INDIVIDUAL	UPPER 90% CL INDIVIDUAL
67.00000000	71.05695298	-4.05695298	62.39118507	79.72272088
52.00000000	52.91079369	-0.91079369	44.11744555	61.70414184
51.00000000	50.87485919	0.12514081	42.19055697	59.55916142
49.00000000	48.33503604	0.66496396	39.26191991	57.40815217
45.00000000	47.11140909	-2.11140909	38.85094649	55.37187170
48.00000000	47.68567883	0.31432117	39.23257359	56.13878408
48.00000000	49.84740361	-1.84740361	41.49975477	58.19505245
40.00000000	40.22025586	-0.22025586	30.53291885	49.90759238
60.00000000	54.33393797	5.66606203	46.26929340	62.39858255
58.00000000	53.90484797	4.09515203	45.75555875	62.05413720
48.00000000	51.95109911	-3.95109911	43.41271288	60.48948535
49.00000000	50.35144037	-1.35144037	42.03450276	58.66837798
49.00000000	55.42708707	-6.42708707	47.38458269	63.46959145
61.00000000	60.07147004	0.92852996	51.42798084	68.71495924
62.00000000	58.18636664	3.81363336	50.12455476	66.24817853
70.00000000	66.97743085	3.02256915	58.33408731	75.62077439
43.00000000	45.31993704	-2.31993704	37.25559250	53.38428159
41.00000000	48.19281165	-7.19281165	40.39120393	55.99441937
54.00000000	53.52984078	0.47015922	45.31286263	61.74681894
50.00000000	48.21732098	1.78267902	38.71700309	57.71763887
60.00000000	53.51203053	6.48796947	44.91495977	62.10910128
47.00000000	47.79010477	-0.79010477	39.26642490	56.31378463
60.00000000	61.96066327	-1.96066327	52.92543082	70.99589572
67.00000000	65.11537497	1.88462503	56.01287291	74.21787703
65.00000000	64.82201575	0.17798425	55.77053225	73.87349926
59.00000000	53.46686955	5.53313045	45.30636205	61.62737705
65.00000000	62.73184088	2.26815912	54.31090401	71.15277774
61.00000000	67.17379051	-6.17379051	59.41828208	74.92929893

OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 90% CL INDIVIDUAL	UPPER 90% CL INDIVIDUAL
61.00000000	61.77833773	-0.77833773	53.98685829	69.56981717
63.00000000	67.23971709	-4.23971709	58.97248256	75.50695161
70.00000000	66.90918295	3.09081705	58.89294750	74.92541840
67.00000000	61.73150331	5.26849669	53.09546302	70.36754359
60.00000000	59.27045682	0.72954318	50.80876871	67.73214494
63.00000000	65.93962724	-2.93962724	57.98282647	73.89642802
58.00000000	58.79550963	-0.79550963	50.03137087	67.55964838
75.00000000	75.53761888	-0.53761888	66.85058785	84.22464992
59.00000000	60.12093888	-1.12093888	51.76125900	68.48061876
80.00000000	79.50211421	0.49788579	71.12416595	87.88006247
62.00000000	62.76981930	-0.76981930	54.37232466	71.16681395
62.00000000	66.90626715	-4.90626715	59.00060816	74.81192613
75.00000000	77.17192897	-2.17192897	68.38421680	85.95964114
79.00000000	74.59269706	4.40730294	66.38460107	82.80079305
58.00000000	55.51045835	2.48954165	47.53621218	63.48470452
67.00000000	63.14515242	3.85484758	54.88112498	71.40917986

(Table VII). The highest residual was -7.2, with 20 of the 44 predictions having a residual of less than 2.0; the standard deviation was 4.2.

To improve the equation, another approach was tried. All the sites were sorted by SSOIL and a backwards and stepwise was run on each soil source yielding a set of variables for each soil type. Since the loess category had only one site and the glacial had 2 sites, they were reclassified into the colluvium-residuum category putting all the sites in 2 categories.

The best variables for each soil source were then used with the source of soil as the only class to form a prediction equation for each (Tables VIII, IX, X, XI, XII, XIII). The equations are used in the same format as the first analysis; the predicted value is the total of the sum of the variables multiplied by the estimate of each with the intercept added.

The regression of the soil variables of alluvial soils had an R-square of .94 using 12 variables. It was the biggest value for any procedure tried. The 90% confidence interval was about 14, and the mean square for error was 11.44. The largest residual was 4.36 with 13 out of 21 predictions being less than 2.0 units in deviation. The regression of the best variables of colluvium-residuum soils were not as good, the R-square being .86 and the 90% confidence interval of about 19 units.

An ideal method would involve variables that could easily be measured by the field forester with no laboratory work required.

TABLE VIII REGRESSION MODEL FOR ALLUVIUM

DEPENDENT VARIABLE: SI

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
MODEL	11	1612.19342769	146.56303888
ERROR	9	102.94942945	11.43882549
CORRECTED TOTAL	20	1715.14285714	

F VALUE	PR > F	R-SQUARE	C.V.
12.81	0.0003	0.939976	5.0914
	STD DEV		SI MEAN
	3.38213328		66.42857143

SOURCE	DF	TYPE IV SS	F VALUE	PR > F
SSCIL	0	0.00000000	.	.
PCSLOPE	1	128.52563804	11.24	0.0085
ESD	1	250.71946339	21.92	0.0011
WHCRL	1	602.22680718	52.65	0.0001
WHCP	1	277.28762616	24.24	0.0008
PHB2	1	197.79950747	17.29	0.0025
PHC	1	105.12098572	9.19	0.0142
LOWPH	1	178.13565246	15.57	0.0034
HIGHPH	1	215.61395558	18.85	0.0019
SCB2	1	852.01200364	74.48	0.0001
ESDRL	1	553.60463887	48.40	0.0001
PCCA1	1	118.74422765	10.38	0.0105

TABLE IX

PREDICTION EQUATION FOR ALLUVIUM

PARAMETER		ESTIMATE		T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT		330.41181393	B	8.40	0.0001	39.31529520
SSOIL	1	0.00000000	B	.	.	.
PCSLCPE		10.90578623		3.35	0.0085	3.25351500
ESD		0.82714043		4.68	0.0011	0.17667534
WHCRL		10.32354596		7.26	0.0001	1.42278596
WHCP		-3.72850179		-4.92	0.0008	0.75728583
PHB2		-25.49809496		-4.16	0.0025	6.13176939
PHC		8.89028958		3.03	0.0142	2.93266133
LCWPH		23.60726667		3.95	0.0034	5.98220097
HIGHPH		-28.97957700		-4.34	0.0019	6.67489327
SCB2		-1.45693355		-8.63	0.0001	0.16881367
ESDRL		-2.01448780		-6.96	0.0001	0.28957129
PCCA1		0.64522598		3.22	0.0105	0.20026097

TABLE X

PREDICTED VS. OBSERVED FOR ALLUVIUM

CBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 90% CL INDIVIDUAL	UPPER 90% CL INDIVIDUAL
59.00000000	56.91010197	2.08989803	48.75149343	65.06871050
65.00000000	65.00000000	0.00000000	56.23198848	73.76801152
61.00000000	63.44700300	-2.44700300	56.49749621	70.39650978
63.00000000	65.83772596	-2.83772596	58.30542303	73.37002839
70.00000000	71.47573968	-1.47573968	64.52049387	78.43098549
67.00000000	62.96481409	4.03518591	55.94407359	69.98555459
60.00000000	58.40856012	1.59143988	50.63771741	66.17940283
63.00000000	59.82402436	3.17597564	52.40553264	67.24251607
48.00000000	52.36227617	-4.36227617	44.97202507	59.75252726
58.00000000	59.67762814	-1.67762814	51.37499179	67.98026449
75.00000000	74.23903763	0.76096237	66.43009548	82.04797977
59.00000000	57.66681521	1.33318479	49.93024493	65.40338550
82.00000000	81.23522856	0.76477144	72.98202798	89.48842915
80.00000000	83.25411936	-3.25411936	75.62389185	90.88434688
62.00000000	64.75750572	-2.75750572	56.95654339	72.55846805
62.00000000	62.56080792	-0.56080792	54.83891233	70.28270351
75.00000000	74.71593657	0.28406343	66.00895328	83.42291985
79.00000000	76.18836023	2.81163977	68.62336453	83.74335593
82.00000000	81.14911017	0.85088983	73.25223475	89.04598559
58.00000000	57.32973905	0.67026095	49.50267409	65.15680402
67.00000000	65.99546610	1.00453390	58.30532407	73.68560814

TABLE XI REGRESSION MODEL FOR COLLUVIAL/RESIDUUM

DEPENDENT VARIABLE: SI

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
MODEL	12	1639.78635955	136.64886330
ERROR	13	260.25210199	20.01939246
CORRECTED TOTAL	25	1900.03846154	

F VALUE	PR > F	R-SQUARE	C.V.
6.83	0.0008	0.863028	8.2563
	STD DEV		SI MEAN
	4.47430357		54.19230769

SOURCE	DF	TYPE IV SS	F VALUE	PR > F
SSCIL	0	0.00000000	.	.
TA	1	206.46415417	10.31	0.0068
BDA	1	152.41369809	7.61	0.0162
PCSLOPE	1	566.06369015	28.28	0.0001
ESD	1	528.77501038	26.41	0.0002
WHCP	1	602.72993476	30.11	0.0001
PHA1	1	172.09875149	8.60	0.0117
PHC	1	97.86976561	4.89	0.0456
HIGHPH	1	279.09979346	13.94	0.0025
SCB2	1	311.81152628	15.58	0.0017
PCCB2	1	401.84636759	20.07	0.0006
RATIO	1	33.76019339	1.69	0.2166
ASP	1	152.01149950	7.59	0.0164

TABLE XII

PREDICTION EQUATION FOR COLLUVIAL/RESIDUUM

PARAMETER		ESTIMATE		T FOR HO: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT		-61.65695115	B	-1.41	0.1807	43.58328771
SSOIL	2	0.00000000	B	.	.	.
TA		2.60780714		3.21	0.0063	0.81204218
BDA		36.98012523		2.76	0.0162	13.40237631
PCSLOPE		0.24347463		5.32	0.0001	0.04573746
ESD		0.76537005		5.14	0.0002	0.14892239
WHCP		-3.64532793		-5.49	0.0001	0.66435571
PHA1		13.73771189		2.93	0.0117	4.68544658
PHC		5.54244112		2.21	0.0456	2.50669942
HIGHPH		-19.00212940		-3.73	0.0025	5.08916174
SCB2		0.96482571		3.95	0.0017	0.24447150
PCCB2		-1.25892832		-4.48	0.0006	0.28099360
RATIO		0.91204310		1.30	0.2166	0.70232536
ASP		-0.02574106		-2.76	0.0164	0.00934144

TABLE XIII

PREDICTED VS. OBSERVED FOR COLLUVIAL/RESIDUUM

OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 90% CL INDIVIDUAL	UPPER 90% CL INDIVIDUAL
67.00000000	69.68855686	-2.68855686	60.06027374	79.31683998
52.00000000	56.95192525	-4.95192525	46.85850284	67.04534766
51.00000000	49.02479849	1.97520151	39.51330320	58.53629379
49.00000000	51.21737067	-2.21737067	42.26768453	60.16705681
45.00000000	45.54341988	-0.54341988	34.93091055	56.15592921
48.00000000	45.72203690	2.27796310	35.96964109	55.47443271
48.00000000	53.82028642	-5.82028642	43.88553601	63.75503432
40.00000000	40.24521473	-0.24521473	29.09430091	51.39612854
60.00000000	57.25470621	2.74529379	48.23616242	66.27325000
58.00000000	57.57122190	0.42877810	47.84303200	67.29941180
48.00000000	45.21593107	2.78406893	35.65442640	54.77743574
49.00000000	54.18210008	-5.18210008	45.11089090	63.25330925
49.00000000	47.43601054	1.56398946	37.84759844	57.02442264
61.00000000	59.95910565	1.04089435	50.50052602	69.41768527
62.00000000	60.49359815	1.50640185	51.08967674	69.89751957
70.00000000	61.98732686	8.01267314	52.77761139	71.19704234
65.00000000	60.64339171	4.35660829	50.85469533	70.43208809
43.00000000	41.86704390	1.13295610	32.51227760	51.22181020
41.00000000	45.86556290	-4.86556290	37.01742936	54.71369645
54.00000000	54.02343018	-0.02343018	44.70627447	63.34058589
50.00000000	50.34431706	-0.34431706	39.40100430	61.28762983
60.00000000	55.91415057	4.08584943	46.29918574	65.52911539
47.00000000	47.49935919	-0.49935919	38.26149612	56.73722226
60.00000000	61.67316609	-1.67316609	52.01013970	71.33619248
67.00000000	68.59923067	-1.59923067	58.05894973	79.13951161
65.00000000	66.25673809	-1.25673809	56.36060312	76.15287306

With this in mind a third approach was tried, with the variables picked according to their ease of measurement. They were: SSOIL, TOP, SURVEG, ESDRL, TA, PCSLOPE, PHA1, and ASP. The variables were entered in the model using the qualitative variables as classes.

After many runs with different combination of variables, it was found that TOP was used as the class and TA and PCSLOPE as the other variables (Tables XIV, XV, XVI). The same 4 cards as in the first procedure were dropped because of high residuals. This approach had a R-square of .62 which seems low, but it must be remembered that only 3 variables are used to explain 62% of the model statement where in the best approach using soils as the class and getting an R-square of .94, 11 variables had to be observed.

The 90% confidence interval of about 25 units would eliminate this equation from being used in the field for this spread is too great to be used on black walnut. There were 5 predictions that had a residual greater than 10 units, and an error of this type could cost the producer greatly. For reliable use of an equation of this type, you should have a 90% confidence interval of no more than about 10 units. This would yield estimated site indexes that could be used for the management practices. So far no one has developed such a method for estimation. This study using the approach of classification by alluvial soils came close to this mark.

As found in this study, it would be best to use different approaches for different types of sites. If the site was of alluvial source, it would be best to rate it using the prediction equation

TABLE XIV

REGRESSION MODEL FOR EASY TO MEASURE VARIABLES

DEPENDENT VARIABLE: SI

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE
MODEL	7	2590.77617925	370.11088275
ERROR	36	1571.76927529	43.66025765
CORRECTED TOTAL	43	4162.54545455	

F VALUE	PR > F	R-SQUARE	C.V.
8.48	0.0001	0.622402	11.2339
	STD DEV		SI MEAN
	6.60759091	.	58.81818182

SOURCE	DF	TYPE IV SS	F VALUE	PR > F
TOP	5	985.58981762	4.51	0.0027
TA	1	1076.62323426	24.66	0.0001
PCSLOPE	1	56.77895337	1.30	0.2617

TABLE XV

PREDICTION EQUATION FOR EASY TO MEASURE VARIABLES

PARAMETER		ESTIMATE		T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT		34.88831961	B	7.74	0.0001	4.50540903
TOP	2	13.56761623	B	2.91	0.0061	4.66099064
	3	3.26732466	B	0.72	0.4791	4.56807702
	4	13.10376424	B	3.85	0.0005	3.40332607
	5	11.88131851	B	3.73	0.0007	3.18131890
	8	11.09126203	B	2.54	0.0154	4.35954097
	9	0.00000000	B	.	.	.
TA		1.27294906		4.97	0.0001	0.25634349
PCSLOPE		0.06028220		1.14	0.2617	0.05286139

TABLE XVI PREDICTED VS. OBSERVED FOR EASY TO MEASURE VARIABLES

OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 90% CL INDIVIDUAL	UPPER 90% CL INDIVIDUAL
70.00000000	64.33414655	5.66585345	51.35549734	77.31279575
43.00000000	48.22063220	-5.22063220	36.29597580	60.14528860
41.00000000	47.55050515	-6.55050515	35.74125922	59.35975107
54.00000000	49.79499226	4.20500774	38.00289794	61.58708659
50.00000000	52.33730409	-2.33730409	39.20671642	65.46789177
60.00000000	50.76653032	9.23346968	38.91982308	62.61323755
47.00000000	47.30039364	-0.30039364	34.39659928	60.20418800
60.00000000	64.22284386	-4.22284386	51.01492669	77.43076103
67.00000000	55.42230545	11.57769455	43.71289863	67.13171227
65.00000000	58.43985205	6.56014795	45.03805453	71.84164957
59.00000000	54.40733247	4.59266753	42.36123627	66.45342867
65.00000000	63.38803695	1.61196305	51.62574066	75.15033323
61.00000000	65.86387399	-4.86387399	54.30751794	77.42023004
61.00000000	62.04502682	-1.04502682	50.46785130	73.62220233
63.00000000	59.49912870	3.50087130	47.82757887	71.17067853
70.00000000	67.13682305	2.86317695	55.55502607	78.71862003
67.00000000	64.54042160	2.45957840	52.76188855	76.31895466
60.00000000	56.95323059	3.04676941	45.12455544	68.78190573
63.00000000	68.40977211	-5.40977211	56.78646461	80.03307960
58.00000000	68.40977211	-10.40977211	56.78646461	80.03307960
75.00000000	74.72401407	0.27598593	62.28271722	87.16531091
59.00000000	61.99452349	-2.99452349	50.22733059	73.76171639
80.00000000	76.04746645	3.95253355	63.85126214	88.24367077
62.00000000	65.86387399	-3.86387399	54.30751794	77.42023004
62.00000000	67.13682305	-5.13682305	55.55502607	78.71862003
75.00000000	59.44862537	15.55137463	47.62922546	71.26802529
79.00000000	73.50156834	5.49843166	61.55584549	85.44729119
58.00000000	56.95323059	1.04676941	45.12455544	68.78190573
67.00000000	60.77207776	6.22792224	49.15567838	72.38847713

OBSERVED VALUE	PREDICTED VALUE	RESIDUAL	LOWER 90% CL INDIVIDUAL	UPPER 90% CL INDIVIDUAL
67.00000000	68.35926878	-1.35926878	56.44524952	80.27328804
52.00000000	52.03947937	-0.03947937	40.20816953	63.87078922
51.00000000	52.09077887	-1.09077887	39.16364735	65.01791039
49.00000000	47.60882749	1.39117251	34.69274418	60.52491080
45.00000000	53.98811309	-8.98811309	41.86243542	66.11379076
48.00000000	47.28128497	0.71871503	34.53350839	60.02906156
48.00000000	48.55423403	-0.55423403	35.82381932	61.28464873
40.00000000	53.71333530	-13.71333530	41.51084487	65.91582574
60.00000000	53.84794539	6.15205461	42.20884204	65.48704875
58.00000000	58.70563567	-0.70563567	46.75844680	70.65282453
48.00000000	55.12209214	-7.12209214	42.13445917	68.10972510
49.00000000	61.02298543	-12.02298543	49.25105163	72.79491924
49.00000000	54.10311988	-5.10311988	42.12203326	66.08420650
61.00000000	59.54376132	1.45623868	46.65578227	72.43174037
62.00000000	56.53401121	5.46598879	44.57981441	68.48820801

by SSOIL since the R-square for the best quantitative variables classed by SSOIL was .94 for alluvial soils. If the site was anything but alluvial, it would be best to use topography to class the site since the R-square is .88.

Only 4 variables came out significant in all approaches tested (easy to measure approach omitted due to variables being hand picked) they were: ESD, WHCP, PHC, and HIGHPH. The thickness of A horizon (TA) came out significant in all approaches but for alluvial soils. This is not surprising since most of the alluvial soils have a very thick A horizon (no limiting factor). Four variables that were tested were never significant, they were: DRL, BDRL, SURVEG, AND SCA1. In all 3 approaches at least half of the variables changed significance as a different approach was tried.

While this study uses sites having natural growing trees, most studies are done on plantations and areas where one can obtain many sites on the same soil series. This study, then, is influenced by considered as errors. I tried to get a handle on this natural variation by classifying the sites by topography or source of soil.

One of the problems of classification by topography is that it was extremely difficult to decide between classifications on many occasions. The topography did not always fit exactly out definition or in many cases the topography would be changed by man's influence. This was one of the reasons why the source of soil was tried, it was easier to class the site as alluvial or other. It would be questionable if this study is suitable for use in the field.

Post and Curtis (1970) who estimated site index by soils and topography, stated that their method would not be useful if the standard deviation was 8.4 or above. The highest standard deviation in this study was 4.47, but even with this range, the difference in crop value for black walnut would be great. In another study Phillips (1966), for yellow-poplar, used soil and topography to estimate site index. The highest R-square achieved was .67 for 7 variables.

Many soil-site evaluations (this study included) are made with correlation of the predicted values obtained to some standard observed value. It is believed that this method is not a reliable source of an indicator for accuracy of the prediction (McQuilikin 1976). A better method would involve testing the acquired prediction equation on independent sites. Cases that have been tested this way, have found to be completely unreliable for a site index predictor.

There are many, usually interrelated, variables to be observed when dealing with a natural situation creating many problems when attempting an estimation of the results of these variables observing only a few of them. It may be possible that in the case of the soil-site approach, the soil is not a limiting enough factor for use in obtaining an extremely highly significant prediction equation. If this is gound to be so, a new direction must be followed to find the answer.

CHAPTER VI

SUMMARY AND CONCLUDING REMARKS

The direct estimate of site index that this study used as a standard for comparision might be one of the largest errors in the experiment. These site index curves are based on the tree age 50. Younger stands of 30 years of less deviate from the curves because of the stand-age soil-site interactions (Hannah 1971). Tree growth on loam soils might be very rapid at first and taper off later, or on sandy soils tree growth would start slow and accelerate with age.

Stand density has a great influence on tree height. Northeast Kansas does not have large amounts of natural black walnut occurring together. Instead the walnut trees occur in small patches scattered throughout the woods. Care was taken in selecting the sites, but it was not always possible to avoid low stand densities.

Sampling bias is a major possibility with harmonized site index curves. Sampling is often distorted because of how the land was originally cut. On poor sites, old trees remain and the good sites contain very young stands (Beck and Trousdell 1973). This is evident in northeast Kansas.

The second error in harmonized curves is the assumption that there is a constant curve shape. The variance to site index can change with time (or age) for a stand (Lloyd and Hafley 1977).

Polymorphic curves developed from the stem analysis approach could yield entirely different site index values for the same site (Beck and Trousdell 1973). The problem with using this method on black walnut is that the trees are too valuable to cut down and section to obtain a polymorphic curve for the site. A study of this type could be carried out during the logging of the black walnut if the proper cooperation could be obtained between the loggers and the researchers.

Another problem encountered in this study was the procedure to determine bulk density. This procedure was selected because abundant rocks in many of the profiles prevented other methods from being used. The clod method did not yield the same values when compared to values obtained by other methods. The values on the average were two to three-tenths higher than what was expected, but in relation to each other the values seemed to be consistent.

The higher values could have been the result of the inter-clod spaces not being taken into account. Another reason could be drying of the soils. Soils with a high clay content shrink when drying, causing the air-dry volume to be less than the field-moist sample.

This study is a very positive start towards soil-site evaluation for northeast Kansas. The approach of separating the site by SSOIL and obtaining a prediction equation for each type shows that this could be done for topography with the collection of more sites. You would need the same number of sites as the number of variables tested in each classification for backwards and stepwise regresseion.

With the re-evaluation of the Kellogg site index curves by new computer techniques, a stronger correlation might be obtained. The completion of Dr. W. A. Geyer's site index curves for northeast Kansas could improve the prediction equation further. Both these improvements would still use the soil information collected in this study.

This study showed some of the soil characteristics that had a strong influence on the site index value of the site. It also eliminated several variables from being tested any farther. It was a strong step in the improvement of a soil-site evaluation technique for northeast Kansas and with further work a field-working method could be formed.

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APPENDIXES

APPENDIX A

BULK DENSITY CALCULATIONS

1. $$\frac{\text{Moist weight - dry weight}}{\text{dry weight}} = w$$

2. Moist weight - (w x moist weight) = Adj. dry weight

3. $$\text{B. D.} = \frac{W}{\frac{Wa-Ww}{p_w} - \frac{Wa-W}{p_p}}$$

B.D.= bulk density of soil

W = Adj. dry weight of clod before paraffin coating

Wa = Adj. dry weight of clod with paraffin coating

Ww = Adj. dry weight of clod with paraffin coating in water

p_w = Density of water (1 gm/cc)

p_p = Density of paraffin (0.9 gm/cc)

APPENDIX B

SAMPLE CALCULATION OF

MECHANICAL ANALYSIS

SAND

40 sec. reading	Temp ·F	Corrected 40 sec
39.0	73.4	40.3

(Temp - 67)0.2 = correction factor

(73.4 - 67) 0.2 = 1.3

(50 - corrected 40 sec.) 2 = % sand

(50 - 40.3) 2 = 19.4%

CLAY

2 hr reading	Temp	Corrected 2 hr
11.0	73.4	12.3

2 hr reading x 2 = % clay

12.3 x 2 = 24.6%

SILT

100 - % clay - % sand = % silt

100 - 24.6 - 19.4 = 56.0 %

APPENDIX C

DATA

COUNTY	STOP NO.	OBS	SI	DRL	BDRL	TA	BDA	SSOIL	TOP	PCSLOPE	SURVE(
POTT	2	1	67	34	1.82	16	1.67	4	4	0	2
	5	2	59	25	1.70	6	1.50	1	5	0	2
	6	3	52	13	1.71	13	1.61	2	9	10	2
	7	4	65	34	1.90	12	1.56	1	4	2	2
	8	5	51	17	.	10	1.55	2	3	20	2
	9	6	61	38	1.71	15	1.57	1	5	0	1
	10	7	49	16	1.71	7	1.51	2	3	9	2
	12	8	45	29	1.83	4	1.61	2	4	15	1
	13	9	61	60	.	12	1.61	1	5	0	2
	15(1)	10	48	18	1.79	5	1.34	2	9	100	1
	15(2)	11	48	29	1.74	6	1.40	2	9	100	1
	16	12	40	11	1.49	11	1.50	2	9	80	1
	17	13	60	27	1.78	13	1.54	2	9	40	1
	18	14	58	34	1.96	18	1.39	2	9	15	1
	19	15	63	32	1.60	10	1.52	1	5	0	1
	20	16	48	12	1.67	5	1.42	2	2	5	2
	21	17	49	23	1.96	10	1.47	2	4	5	2
	22	18	70	60	.	16	1.42	1	5	0	1
RILEY	1	19	49	24	1.71	15	1.41	2	9	2	1
	3	20	61	15	1.67	8	1.58	2	2	15	1
	4	21	62	20	1.66	6	1.63	2	4	15	1
	5	22	70	19	1.78	12	1.52	2	2	10	1
	6	23	67	29	1.54	13	1.43	1	4	0	1
	7	24	65	34	1.80	7	1.53	2	9	100	1
	8	25	60	32	1.77	8	1.42	1	5	0	1
GEARY	1	26	43	17	1.71	10	1.47	2	9	10	2
	3	27	41	17	1.67	9	1.46	2	9	20	1
	4	28	54	18	1.83	11	1.45	2	9	15	1
	5	29	63	60	.	17	1.47	1	5	0	1
	7	30	48	15	1.70	10	1.41	1	5	0	1
MARSHALL	2	31	58	60	.	17	1.47	1	5	0	2
	3	32	75	60	.	21	1.56	1	4	0	2
	4	33	50	60	.	4	1.80	4	8	21	2
	6	34	59	60	.	11	1.63	1	4	0	2
	7	35	82	60	.	12	1.39	1	5	0	1
	8	36	80	60	.	23	1.79	1	5	0	2
	9	37	62	60	.	15	1.63	1	5	0	1
NEMAHA	1	38	62	60	.	16	1.77	1	5	0	1
SHAWNEE	1	39	75	33	.	9	1.64	1	4	0	2
JEFF	1	40	79	37	2.01	21	1.62	1	5	0	1
	5,6	41	60	24	1.92	12	1.51	2	9	10	1
	7	42	47	22	1.75	6	1.49	2	3	25	1
	8	43	60	14	1.78	14	1.49	2	8	7	1
DOUGLASS	8	44	82	60	.	13	1.40	1	5	0	1
	9	45	58	51	1.66	8	1.64	1	5	0	1
	11	46	67	60	.	11	1.66	1	5	0	1
WYANDOTE	3	47	67	42	1.90	14	1.44	3	9	45	2
	4	48	65	22	1.96	6	1.40	2	8	80	1

ESD	WHCRL	WHCP	PHA1	PHB2	PHC	LUWPH	HIGHPH	SCB2	SCA1
55.7	7.1	12.2	7.6	5.7	6.6	5.7	7.6	79.2	80.6
27.0	4.5	5.0	7.4	7.8	7.9	7.4	7.9	73.0	77.2
60.0	2.6	14.4	7.2	8.3	8.3	7.2	8.3	81.0	76.6
60.0	6.5	11.3	7.8	6.8	6.2	6.2	7.8	73.0	70.2
11.3	1.6	2.3	7.4	7.6	7.9	6.8	8.2	80.6	76.2
46.0	9.2	11.2	7.7	7.2	7.2	7.0	7.7	82.6	79.0
60.0	3.2	13.0	7.4	5.9	6.2	5.9	7.4	76.6	77.0
34.7	4.4	7.4	7.1	7.5	7.7	6.8	7.7	77.0	80.0
60.0	12.6	12.6	7.1	7.0	7.5	7.0	7.7	80.6	79.6
30.1	1.8	5.6	7.5	8.0	8.7	7.5	8.7	64.6	76.6
31.5	6.5	6.5	8.0	8.1	7.5	7.5	8.1	76.6	71.0
8.0	1.1	11.4	8.0	8.2	8.5	8.0	8.5	74.8	72.4
21.8	2.5	4.4	7.6	7.9	7.6	7.6	8.0	78.0	79.2
60.0	7.1	13.9	7.5	7.8	7.4	6.8	8.0	82.2	75.2
60.0	5.8	10.9	7.9	7.8	7.9	7.7	7.9	72.8	75.8
57.0	1.9	14.0	7.3	6.7	6.3	6.3	7.3	81.8	78.8
60.0	3.5	14.5	7.1	6.0	6.7	5.9	7.1	85.2	81.2
60.0	12.1	12.1	7.6	7.7	7.9	7.6	7.9	72.8	75.6
40.9	5.2	9.1	7.6	8.4	8.2	7.6	8.6	76.8	79.2
60.0	3.0	14.3	6.6	6.0	5.9	5.9	6.6	79.8	78.8
40.0	4.1	9.1	7.6	7.6	7.7	7.4	7.8	78.2	76.6
60.0	3.8	14.1	7.4	6.2	6.4	6.1	7.4	85.2	79.8
55.8	5.8	12.1	6.6	6.6	7.7	6.6	7.7	79.4	78.2
35.6	5.5	8.4	7.3	7.8	7.9	7.3	7.9	74.8	73.8
60.0	7.3	13.7	7.5	5.8	7.4	5.6	7.5	86.8	83.2
60.0	4.0	14.0	7.1	5.9	6.5	5.9	7.5	83.8	79.8
40.2	3.2	9.2	6.9	7.2	7.6	6.9	7.6	80.6	80.6
43.9	3.3	8.3	7.1	5.8	5.9	5.8	7.1	78.4	72.6
60.0	13.2	13.2	7.3	7.7	7.4	7.3	7.7	81.4	80.4
45.7	3.3	10.2	7.2	6.7	7.6	6.5	7.6	82.8	81.8
60.0	12.0	12.0	6.7	5.8	5.4	5.4	6.9	81.8	81.8
60.0	9.2	9.2	7.3	7.6	7.6	6.8	7.6	47.6	36.2
36.1	3.2	3.2	7.2	7.7	8.0	7.2	8.0	35.3	43.0
60.0	11.0	11.0	7.5	7.6	7.5	7.3	7.6	78.6	73.6
60.0	12.5	12.5	7.1	6.1	7.4	6.1	7.5	83.6	81.8
60.0	11.4	11.4	7.0	7.5	7.5	6.8	7.5	57.6	74.0
60.0	12.5	12.5	7.3	7.2	8.2	7.2	8.2	81.2	73.2
60.0	10.9	10.9	7.3	7.0	7.0	6.8	7.4	72.8	45.8
60.0	5.1	5.1	7.1	6.7	6.7	6.2	7.1	75.2	42.6
60.0	6.5	10.7	7.5	7.6	7.4	7.3	7.7	59.1	49.2
60.0	5.8	13.7	7.0	6.4	7.0	5.8	7.0	86.0	81.6
18.0	2.8	4.4	7.1	6.8	7.7	6.8	7.9	81.0	77.2
20.2	1.7	4.5	7.0	6.2	6.7	6.0	7.0	86.6	79.2
60.0	14.9	14.9	7.2	6.3	6.4	6.3	7.2	86.6	85.0
44.0	6.1	7.6	7.8	7.9	8.0	7.7	8.3	68.6	64.6
60.0	14.9	14.9	7.8	7.1	7.0	6.8	7.8	84.6	80.6
60.0	13.6	13.6	7.1	5.3	4.7	4.7	7.1	82.6	81.0
22.3	4.4	6.6	7.6	6.3	7.6	6.3	7.6	83.0	78.0

PCCB2	RATIO	ESDRL	ASP	PCCA1
38.0	5.0	32.9	0	25
28.6	12.2	23.8	0	21
27.6	6.2	13.0	270	23
28.6	6.1	34.0	0	17
41.6	8.1	7.4	10	26
33.6	5.5	38.0	0	25
31.6	10.9	16.0	55	18
34.6	19.3	25.7	320	34
19.6	6.7	60.0	0	31
27.6	12.9	9.4	290	24
41.6	12.8	23.5	290	31
27.2	6.8	6.1	230	26
40.0	6.0	13.6	280	29
36.2	4.6	34.0	310	25
21.2	7.3	32.0	0	20
32.2	16.4	9.0	90	18
38.6	8.5	23.0	0	21
22.2	4.6	60.0	0	22
35.8	5.1	21.6	35	16
25.2	10.0	15.0	290	22
32.6	13.0	20.0	0	30
29.8	7.1	18.1	330	17
25.2	6.1	29.0	0	20
37.8	10.7	29.6	70	29
34.2	10.9	32.0	0	19
41.2	8.4	17.0	75	26
34.6	9.0	14.6	270	32
33.2	7.1	17.0	360	17
23.2	4.8	60.0	0	21
31.2	8.3	15.0	0	14
21.2	4.8	60.0	0	20
16.6	2.3	60.0	0	15
15.3	8.8	36.1	5	15
29.6	7.2	60.0	0	24
18.8	7.0	60.0	0	38
15.0	2.5	60.0	0	22
32.6	5.4	58.5	0	26
22.2	4.6	60.0	0	12
18.6	8.4	33.0	0	12
28.3	2.8	37.0	0	13
45.6	7.2	24.0	80	24
35.6	13.5	11.0	45	23
42.2	6.2	7.4	210	24
34.0	6.7	60.0	0	21
27.6	8.6	36.0	0	27
29.2	7.7	60.0	0	25
31.6	5.9	42.0	30	9
30.2	13.8	11.0	340	18

SOIL-SITE EVALUATION FOR
BLACK WALNUT IN NORTHEAST KANSAS

by

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A soil-site evaluation was made from forty-eight plots scattered throughout northeast Kansas. These plots were selected for their natural occurring black walnut growing in a wooded enviroment. The trees were bored and measured to obtain a direct estimate of site index. The site index curves used were base age fifty, from Kellogg's data in the Midwest.

At every site the profile was exposed and the soil horizons diagnosed. Samples were collected and the topography of the site was described.

Physical soil properties were selected as quantitative variables and the topography, soil source, and surface vegetation were used as qualitative variables for sorting. Three approaches were tried: 1./all variables on all sites were used in stepwise and backwards regression to obtain a prediction equation, 2./the sites were sorted by the source soil and a prediction equation obtained for each, and 3./the easy to measure variables were used to obtain an equation.

The predicted values were compared with the observed values for each site and a 90% confidence interval was given for each. The best approach was sorting by alluvial soils with a R-square of .94. With all the sites, using topography as the class, R-square was .88. Using the easy to measure variables proved to be poorly related with a R-square of .62; this approach used three variables.