SITE INDEX

of New Jersey Sweetgum Stands Related to Soil and Water-Table Characteristics

John J. Phillips & Marco L. Markley

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Contents

Introduction

AS FOREST management becomes more intensive, there is increasing need for knowledge of the differences in the productiveness of individual land areas or sites. For example, highly productive forest lands justify far more investment in cultural measures than do those of low productivity or, more specifically, conversion from stands of low-value species may be economically feasible on the better sites, but not on the poor sites.

PREVIOUS STUDIES

Very little work has been done on species typical of wet sites in the Northeast. However, in the South, Broadfoot and Krinard (1959) related a number of soil characteristics and soil types to the site index of sweetgum. For soils outside the Missisippi River flood plain, they found an increase in site index with increased exchangeable potassium and decreased clay content, both sampled in the 3- to 4-foot soil layer.

On sites adjacent to reservoirs with fluctuating levels in Tennessee, sweetgum plantations grew best on soils with deep surface layers and permeable subsoils, poorest on poorly drained sites with compact subsoils (Silker 1948). Minckler (1946) also found that sweetgum grew better on friable soils than on plastic ones.

In Maryland, Trenk (1929) observed that the best growth of sweetgum occurred on alluvial sites and on wet soils high in clay, the poorest growth on well-drained clay or gravelly-clay soils.

GENERAL APPROACHES

The usual method of determining site productivity of forest land is to first obtain the heights and ages of several dominant and codominant trees and then read the site-index value (height of dominant trees, in feet, usually at age 50) from a set of existing site-index curves for a particular tree species. However, all land areas are not now occupied by stands of trees suitable for use in making a determination of site index. And it is desirable to be able to estimate site index from observations or measurements of certain features of the land itself—usually soil and topography.

Two approaches are used to establish relationships between site index and the soil and topography. One approach is to correlate site index with various measurable factors of the soil and topography, such as soil texture and position on slope. The other approach is to determine the average site index for each of the soil types on which a tree species commonly occurs.

In the study reported in this paper, both approaches were used in sweetgum (*Liquidambar styraciflua* L.) stands on the Coastal Plain of New Jersey. There sweetgum is a prized species: it, yellow-poplar, and oaks are the valuable components of forest stands on the more productive sites. On these soils, sweetgum frequently forms relatively pure stands in abandoned fields or pastures. And local basket mills rely heavily on sweetgum logs for their veneer.

Study Area

In New Jersey, sweetgum stands are usually confined to the Coastal Plain. However, the species does extend up some of the river valleys to the Piedmont (Stone 1911), where sweetgum usually occurs as scattered trees in stands of other species. Sweetgum is generally absent from the coarse sand and gravel deposits of the Pine Region, but occasional clumps or stands occur in the Coast District (fig. 1) delineated by Stone.

Pure or nearly pure stands of sweetgum are common in the inner Coastal Plain, particularly in portions of Middlesex, Monmouth, Burlington, and Salem Counties. Such stands are nearly always even-aged and of old-field origin, having developed for the most part on soils too wet to be kept in agriculture. Agricul-

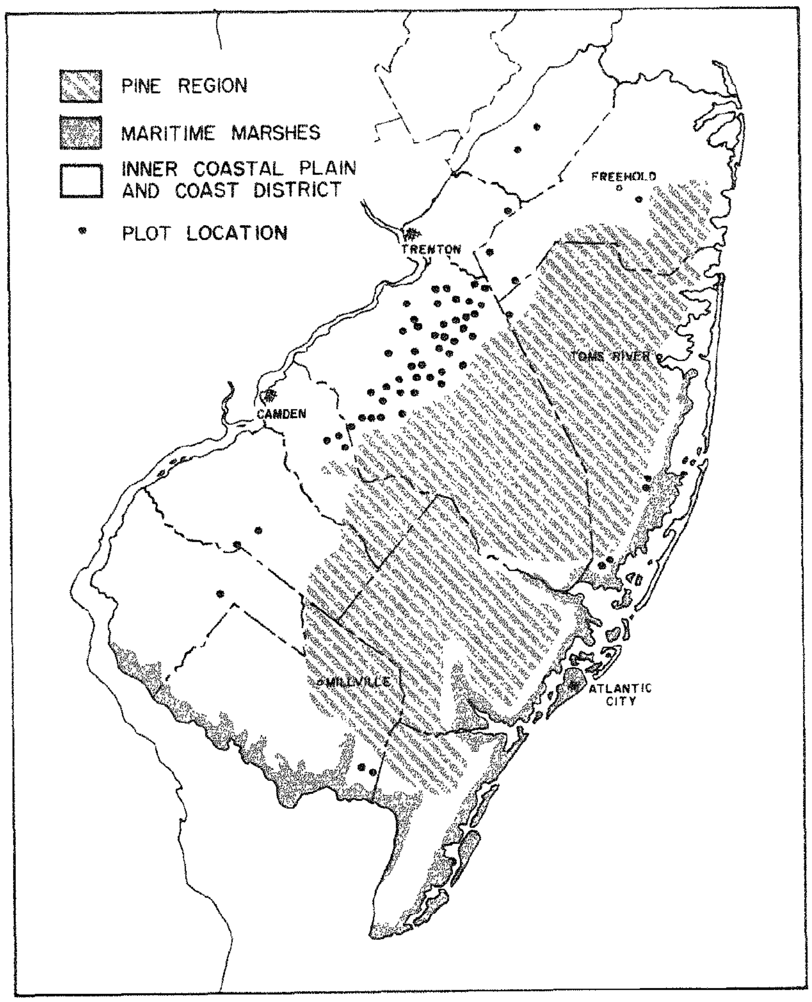


Figure 1. — The subdivisions of the New Jersey Coastal Plain (after Stone 1911), and the plot locations of the sweetgum site study.

ture in the inner Coastal Plain is intensive, and most woodlots there are small and scattered.

Topographically, the New Jersey Coastal Plain is more rolling than most of the rest of the Atlantic Coastal Plain. Soils in the inner Coastal Plain vary in texture from sands to clays. Where well-drained, the soils are intergrades between the Gray-Brown Podzolic and Red-Yellow Podzolic soil groups. Where poorly or very poorly drained, the soils are Low-Humic Gleys or Humic Gleys. Type and age of parent soil materials vary from the older beds of glauconitic, Tertiary, and Cretaceous deposits near the Delaware River to the younger beds of lacustrine, aeolian, and alluvial deposits of Pleistocene origin. The latter deposits overlie the older beds in many places.

STANDS

All of the sweetgum stands studied were even-aged, originating in abandoned fields (fig. 2). Dominant and codominant trees were 30 to 65 years old, with a maximum range in age of 6 to 8 years within individual stands. All stands were dense, and the basal areas ranged from 117 to 240 square feet per acre.

In composition, the stands were fairly uniform on all plots. Sweetgum made up more than 90 percent of the overstory canopy, with some red maples in the intermediate and overtopped crown classes. In some stands a few pin oaks were dominant along with the sweetgums. However, both sweetgum and pin oak were sparsely represented or absent in the reproduction, except near the edges of the stands. Red maple predominated in the reproduction, although some stems of other species also occurred, chiefly willow oak, swamp white oak, northern red oak, holly, ash, beech, dogwood, and sassafras. Characteristic shrubs were southern arrowwood (*Viburnum dentatum*), spicebush (*Lindera benzoin*), high-bush blueberry (*Vaccinium* spp.), and sweet pepperbush (*Clethra alnifolia*); but poison ivy (*Rhus radicans*) was even more common. Wild garlic (*Allium* spp.) was the most prevalent herb.

Figure 2. — A typical even-aged sweetgum stand on a Weeksville fine sandy loam soil in New Jersey. This stand is 41 years old and has grown more than 100 merchantable cubic feet per acre per year. Its dominants are about 11 inches in diameter breast high.

SOILS

Soils were predominantly wet: poorly drained and very poorly drained soils made up 84 percent of the total number of plots. This high proportion was apparently due to two factors: (1) sweetgum needs moist or wet sites for successful establishment and rapid growth, and (2) wet soils are usually the first to be abandoned from agricultural use.

As might be expected, all of the study areas were in relatively flat areas or small depressions. Slopes generally averaged less than 1 percent, with a maximum of 4 percent.

Nearly all of the stands studied had mineral soils. Organic soils supporting sweetgum were found in only three stands, and only one of these stands was stocked well enough to be included in the study. This area had a shallow layer of muck, but its drainage had been improved by a nearby outlet ditch.

Most of the sites had surface drainage ditches, relics from their use as fields. The ditches varied in their state of repair and efficiency. Some of them, as the one in the muck area, appeared to be at least partially effective in lowering the groundwater table. Others seemed too poorly maintained to have any appreciable effect, especially in the heavy-textured soils. And there were no detectable relationships of site index to distance from ditches or to their depth.

Study Methods

Three to ten plots, each 0.1 acre in size, were established on each soil series commonly supporting sweetgum stands. Several plots were also installed on the less common sweetgum soils to determine what soil characteristics affected site index in these particular areas. A total of 61 plots were included in the study.

Each plot had to meet certain requirements. Soil conditions had to be relatively uniform, uniformity being determined from at least three auger holes. The stand had to be even-aged, and had to contain at least 10 dominant or codominant sweetgums 30 to 65 years old. Sampled trees had to be of seed origin, and free of any apparent damage by fire, grazing, dieback, or blight.

Total heights of 10 dominant and codominant trees on each plot were measured with a Haga altimeter, and increment cores were taken at breast height. These cores were dyed with a phloroglucinol solution to make the annual rings more prominent (Patterson 1959). Ring counts were made under a low power (12×) microscope, and 3 years were added to obtain total age from seed. From the height and age data of each plot, a site-index value was obtained by using curves (base age of 50 years) derived from Trenk's (1929) tables. Data from the present study were used to construct height-age curves by site classes, but these were so similar to Trenk's data that his were used.

A detailed soil description was prepared for each plot; this included depth measurements that were used in later statistical analyses. In addition, soil samples (each a composite from three holes) were taken of the surface 6-inch horizon and of the B_2 horizon. Sampling for the latter started 2 inches below the top of the B_2, and usually extended 6 inches more in depth.

The soil samples were analyzed for texture and reaction. Texture samples were analyzed by the Bouyoucos hydrometer method, as modified by Wilde and Voigt (1955)—except that the samples were allowed to rehydrate overnight in the dispersing solution. The selection of this period was arbitrary, since the minimum time necessary was unknown. However, tests with plastic soils gave higher clay values with overnight rehydration than with the usual 15-minute treatment. The samples of the B_2 horizons were separated into four textural fractions: coarse sand (2.0 to 0.25 mm.), fine sand (0.25 to 0.05 mm.), silt (0.05 to 0.002 mm.), and clay (less than 0.002 mm.). Samples of the A-horizons contained too much organic matter to permit easy separation of silt from clay; so this was not done.

Soil reaction, acidity in all cases, was determined by using a simple colorimetric pH kit. Generally the soils were rather acid. Surface soil pH averaged about 4.6, and subsoil pH about 4.5. The range of pH in the surface soil was from 4.0 to 5.4, and in the subsoil from 4.0 to 6.2.

Groundwater wells were established in three to five plots on each of the nine principal soil types. Each well was installed by placing a 5-foot length of downspout in an auger hole of 3-inch diameter. A No. 2 tin can was placed on top to keep foreign material out of the pipe. Wells were measured five times during the 1960 growing season so that average, high, and low water depths could be determined for each plot.

Groundwater depths cannot be easily used in site-index prediction, since they require at least a year's measurements, but they were useful in providing information on relationships between the groundwater regime and sweetgum growth.

Results

WELL MEASUREMENTS AND SITE INDEX

Water-table relationships alone could probably be used to explain about half of the variation in site index found in New Jersey sweetgum stands. At least for the 27 wells used in the analysis (3 were discarded because of artesian properties and lack of complete data), the resulting equation based on average depth and maximum fluctuation of water table during the growing season explained more than half of the variation in site index (fig. 3).

The highest site-index values were correlated with an average depth of 20 inches to free water, and with little fluctuation in the level of the water table. The lowest values were correlated with very high or very low water tables and with fluctuations of 2 feet or more. As figure 3 indicates, fluctuations (range in depth to free water) greater than 24 inches have little effect on site index; here other soil properties appear to become more important than water-table fluctuations, although average depth to water is still important.

Recent alluvial deposits within the Delaware Valley provided the most consistent data, and had consistently high site-index values. Such areas are composed of mixed materials that are being currently deposited by nearby streams. Depth to the water table is usually related to the height of the land surface above the stream, and it fluctuates little because the level of the water table is in turn controlled by the stream.

One exception occurs when this alluvial material is underlain by fine-textured, slowly permeable layers. Here the water table may be above the stream surface; and fluctuations in the depth of the water table are affected by the size of the watershed area.

In the mature hydromorphic soils, with well-developed horizons and no recent alluvial deposits,[1] the correlation between site index and water-table conditions was affected by the type of subsoil. The correlation was better for soils having friable subsoils than for those with plastic subsoils, although both followed the same general trend. As a rule, site index seems less dependent on water-table levels in soils having plastic subsoils than in those with friable subsoils.

[1] This definition of mature soils agrees with that given in the U. S. Dept. Agr. Yearbook of Agriculture. 1938: "A soil with well developed characteristics produced by the natural processes of soil formation, and in equilibrium with its environment."

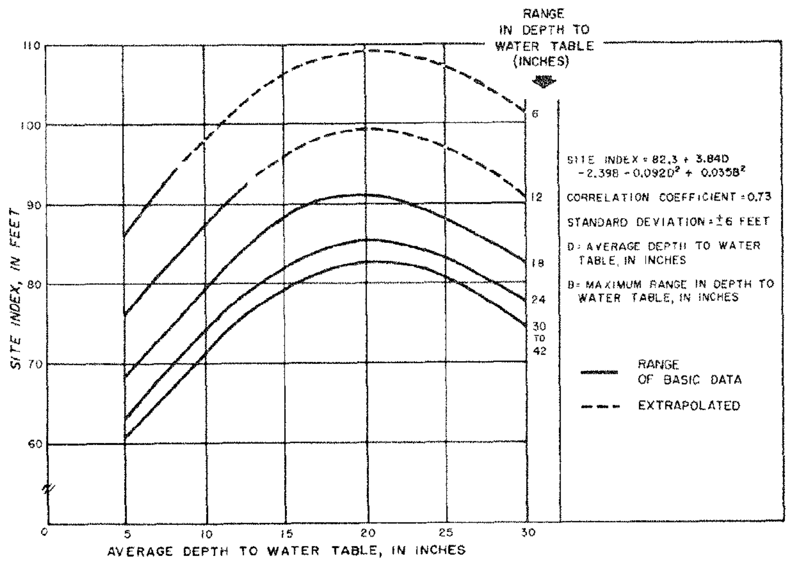


Figure 3. — Site index for sweetgum, as related to fluctuation in depth to water table during the growing season and to average depth to the water table.

Observations during the study indicate that the depth of sweetgum rooting is affected by subsoil consistence and by summer water levels. Rooting was observed to be deeper in soils with plastic subsoils than in those with friable ones, and to increase with increased depth of summer water levels. The rooting depth was little affected by high water during the winter, but of course nearly all the study areas had high water levels then.

SOIL FACTORS AND SITE INDEX

Equation for Mature Soils

A number of soil characteristics or factors were analyzed to determine their degree of correlation with site index. Of these, texture and thickness of the B_2 horizon, along with a factor indicating permeability, gave the best correlation for mature soils.

There was a small, but significant, negative correlation between site index and age before removing the effects of soil factors. After they were removed, plotting age against the deviations from the regression failed to reveal any further correlation. The apparent relationship of age and soil can probably be explained by the fact that some of the soil factors, especially texture, influenced the timing of field abandonment from agricultural crop production.

The final equation relating soil factors to site index is:

$$\text{Site index} = 26.4 + 0.49X_1 + 1.49X_2 - 0.015X_3 + 0.78X_4 - 0.023X_5 + 1.38X_6 - 0.049X_7$$

where:

X_1 = per cent clay in the B_2 horizon.
X_2 = percent fine sand in the B_2 horizon.
$X_3 = (X_2)^2$.
X_4 = difference between percent silt plus clay in the B_2 horizon and percent silt plus clay in the A horizon.
$X_5 = (X_4)^2$.
X_6 = positive difference between 12 inches and the thickness of the B_2 horizon in inches.
$X_7 = (X_6)^2$.

Table 1 gives readily available and usable site-index values derived from the final equation. With this table and appropriate knowledge of the soil factors or variables of a given area, the site index can be estimated.

The multiple correlation coefficient for the equation is 0.817, and the standard error of estimate is $\pm$ 5.7 feet. The equation and the variables are all highly significant. Of the four variables, clay and fine sand were the most important, together removing about 50 percent of the total variation. However, each variable was significant at the 1-percent level when the effects of the other three were eliminated.

Site index increased linearly with clay content of the B_2 horizon throughout the sampled range of 5 to 55 percent. The increase was about 5 feet for each 10-percent increase in clay. The difference in site index at the two extremes was about 24 feet.

The correlation between site index and the fine sand of the B_2 horizon was curvilinear (fig. 4). Site index increased as the proportion of fine sand increased from 15 to 50 percent, although the rate of increase declined above 40 percent. Between 50 and 70 percent fine sand, the site index declined. The increase in site index between 15 and 50 percent of fine sand in the B_2 horizon was 18 feet; and the decrease in site index between 50 and 70 percent was 7 feet.

The inclusion of separate values for clay and fine sand gave a significantly better relationship than the use of silt-plus-clay content, which also had a curvilinear relationship with site index. The proportions of silt and of coarse sand, as well as the product

Table 1. — *Predicting sweetgum site index, in feet, on mature soils in the New Jersey Coastal Plain*[1]

A

Fine sand in B_2 horizon (percent)	Clay content of B_2 horizon, in percent—						
	5	10	20	30	40	50	55
15	48	50	55	60	65	70	72
20	53	55	60	65	70	75	77
25	56	58	63	68	73	78	80
30	60	62	67	72	77	82	84
40	65	67	72	77	82	87	89
50	66	68	73	78	83	88	—
60	64	66	71	76	81	—	—
70	59	61	66	71	—	—	—

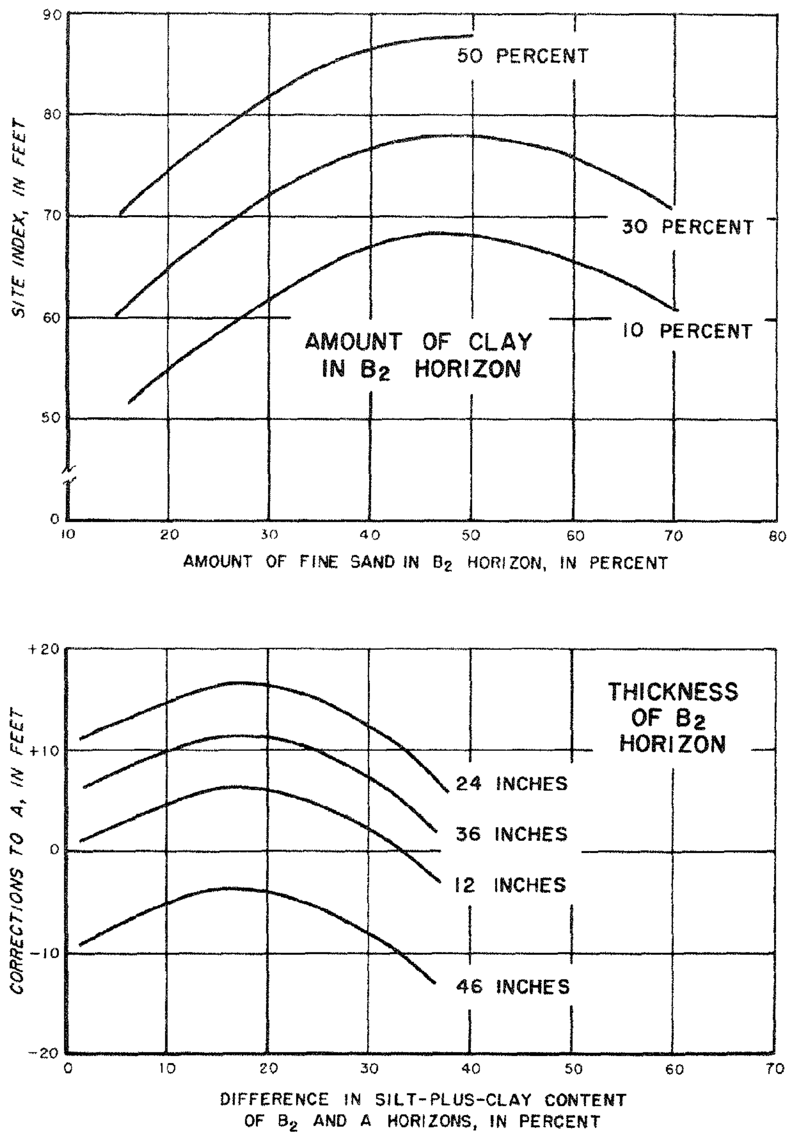
B

Thickness of B_2 horizon[2] (inches)	Difference in silt-plus-clay content of the B_2 and A horizons, in percent									
	1	5	9	13	17	21	25	29	33	37
6	7	9	11	12	13	12	11	9	7	3
8	6	8	10	11	12	11	10	8	6	2
10	4	6	8	9	10	9	8	6	4	0
12	1	3	5	6	7	6	5	3	1	−3
14	4	6	8	9	10	9	8	6	4	0
16	6	8	10	11	12	11	10	8	6	2
18	7	9	11	12	13	12	11	9	7	3
20	9	11	13	14	15	14	13	11	9	5
22	10	12	14	15	16	15	14	12	10	6
24	11	13	15	16	17	16	15	13	11	7
26	11	13	15	16	17	16	15	13	11	7
28	11	13	15	16	17	16	15	13	11	7
30	10	12	14	15	16	15	14	12	10	6
32	8	10	12	13	14	13	12	10	8	4
34	7	9	11	12	13	12	11	9	7	3
36	6	8	10	11	12	11	10	8	6	2
38	4	6	8	9	10	9	8	6	4	0
40	1	3	5	6	7	6	5	3	1	−3
42	−2	0	2	3	4	3	2	0	−2	−6
44	−5	−3	−1	0	1	0	−1	−3	−5	−9
46	−9	−7	−5	−4	−3	−4	−5	−7	−9	−13

[1] First obtain base value in A, then correct as indicated in B. Final site index is the result of adding these two values.

[2] Measured to the bottom of the B_2 or to a depth of 55 inches.

Figure 4. — Effect of certain soil factors on the site index for sweetgum.



of fine sand and clay separates, lacked significance after the individual effects of clay and fine sand were removed.

The difference in the silt-plus-clay contents of the A and B_2 horizons is an index of permeability in the sampled soils. In these, the B_2 horizon usually has a higher content of silt and clay, and where the textural change is very great, a zone of perched water occurs above the less permeable horizon.

A change in texture between the A and B_2 horizons appears favorable for the growth of sweetgum, with a 17- or 18-percent difference being optimum—resulting in an increase of about 7 feet in site index (fig. 4). Beyond this optimum, site index declined. When the difference between the A and B_2 horizons in their silt-plus-clay content reached 38 percent—the maximum found in this study—the site index was 10 feet less than at optimum.

The relationship between thickness of the B_2 horizon and site index is not clear. Where the B_2 horizon was thin, site index was generally good, everything else being equal. However, as the thickness of the B_2 horizon approached 12 inches, site index declined. Then, with further increases in B_2-horizon thickness, site index increased, reaching an optimum at 24 to 28 inches in horizon thickness. Still thicker B_2 horizons were associated with poorer sites. An increase in thickness of the B_2 horizon from 6 to 12 inches was correlated with a decrease of 6 feet in site index; that from 12 to 24 inches, an increase of 10 feet; and that from 28 to 46 inches, a decrease of 20 feet.

Other soil-depth factors (thickness of A_1 horizon, total A-horizon thickness, depth to least permeable layer, depth to mottling, depth to gley layer, and solum thickness) were not significantly related to site index. Nor was there any discernible relationship between site index and soil pH.

Equation Not Applicable to Recent Alluvial Deposits

The site index for sweetgum growing on recent alluvial lands cannot be estimated by using the above equation. On recent alluvial deposits, site index apparently depends primarily on water-table relationships and less on soil texture. Lands having relatively fine-textured glauconitic alluvial deposits showed little range in site index even with considerable variation in texture. Site index on these lands was always higher than it was on coarse textured, non-glauconitic deposits. However, the non-glauconitic deposits had a higher site index than soils of a similar texture that had lower summer water levels.

Effect of Water Table on Equation

Although the above equation was satisfactory for most of the mature soils, on certain areas it was not accurate, largely because of differences in water-table characteristics. Apparently where water tables are high and show little fluctuation, site-index estimates on mature soils might be improved by basing the estimates on both water-table relationships and the soil factors used in the equation.

Also, because the soil-factor equation was derived principally from a population of wet soils, it should not be applied indiscriminately to dry sites. While the equation appeared to estimate site index well for the few drier sites studied, it may not be applicable on all other dry sites. For example, Trenk (1929) observed poor sites for sweetgum on well-drained clays in Maryland, whereas the equation from this study would probably indicate that any soil high in clay content should be a good site for sweetgum.

SOIL SERIES AND SITE INDEX

Soil series recognized by the National Cooperative Soil Survey appear to be a fairly good way of estimating the site index for sweetgum in this study. For site-index values, sufficiently replicated by soil series, an analysis of variance gave a highly significant F value. The mean site index, range in site index, and number of plots are given for each soil in table 2. Soils that were sampled by three or more plots are described briefly in the Appendix.

Site index varied more on certain soil series than it did on others. The least variation encountered, 2 feet, was on poorly drained silty Othello soils; somewhat greater variation, 9 feet, occurred on the Adelphia and Bayboro soils and on recent alluvial glauconitic deposits. The most variation, 21 to 23 feet, occurred on Keansburg soils and on those areas with a field designation of Bustleton soils.

There appear to be different reasons for the variation in site index found within the various soil series. For example, one Bustleton plot had a much thicker B_2 horizon than the others sampled; the remainder of the plots on this soil were more nearly uniform in site index. The variation in site index on Keansburg soils seems to be due to texture variation and, to some extent, to ground-water differences.

Table 2. — *Site index for sweetgum by subsoil texture, soil series, and drainage class*

Soil groups, by subsoil texture[1] and soil series	No. plots	Site index,[2] by drainage class: Well drained soils	Moderately well drained soils	Somewhat poorly drained	Poorly drained soils	Very poorly drained soils
MATURE SOILS						
1. Sand-loamy sand:						
Klej	1	—	—	75	—	—
Rutlege	1	—	—	—	—	60
2. Sandy loam:						
Nixonton	1	—	85	—	—	—
Dragston	1	—	—	58	—	—
Fallsington	2	—	—	—	[3]61 (58-64)	—
Pasquotank	1	—	—	—	74	—
Keansburg	10	—	—	—	—	81 (69-92)
Weeksville	3	—	—	—	—	77 (71-86)
Pocomoke	1	—	—	—	—	62
3. Sandy clay loam-clay loam:						
Collington	1	78	—	—	—	—
Mattapex	1	—	83	—	—	—
Adelphia[4]	2	—	85 (81-89)	—	—	—
Adelphia[4]	3	—	—	81 (80-82)	—	—
Bustleton[5]	5	—	—	—	77 (63-84)	—
Othello	3	—	—	—	83 (82-84)	—
Rancocas[5]	5		—	—	—	83 (78-90)
Bayboro	5	—	—	—	—	87 (82-91)
4. Sandy clay:						
Colemantown	2	—	—	—	85 (81-92)	—
Matlock	3	—	—	—	—	72 (70-74)
RECENT ALLUVIAL DEPOSITS						
Glauconitic	6	—	—	—	—	89 (85-94)
Non-glauconitic coarse-textured	2	—	—	—	—	80 (77-82)

[1] The texture given is the average for the B horizons of all plots within the group.

[2] Standard deviation of approximately 7 feet at 50 years for all series with replicated plots.

[3] Figures in parentheses show the range of site index found, and the figure in front of the parenthesis is the mean site-index value for all plots of that soil series.

[4] Adelphia soils may be either moderately well drained or somewhat poorly drained.

[5] Bustleton and Rancocas are temporary field names, not yet approved.

To determine whether or not the soil-series classification included any important factors not considered in the regression equation, the deviation between actual site index and predicted site index (from the equation) was obtained, and then the mean deviation was computed for each soil series. In all but one of the soil series, the mean deviations were ± 3 feet or less, and the amount of variation was not related to mapped drainage class or surface texture.

Measured site index differed consistently from the predicted site index in only one soil—the moderately well-drained Adelphia. This soil was represented by only two plots, both of which were underestimated by 5 feet. By contrast, the predicted and actual site-index values agreed very well on the somewhat poorly drained Adelphia plots. The authors have no explanation for this discrepancy.

Two of the most extreme deviations from the regression estimate were within the Keansburg soil series. Site index for 8 of the 10 plots on this soil was estimated quite well. However, one plot had a site-index value 9 feet above the estimated value, and the site index of the other plot was 12 feet below the estimated value. Both of these deviations are related to ground-water influences. The first plot, wtih a measured site index value above the predicted value, was located about 50 feet from a stream, and therefore had some of the favorable ground-water characteristics of an alluvial site. The other plot, with site index lower than the predicted value, had an excessively high water table. During the 1960 period of measurement, the average depth to water on this plot was only 1 inch, with a range in depth of 7 inches. In such areas, ground-water conditions appear to be more important than soil properties.

The equation estimated site index fairly well on the glauconitic soils, though the soils do present a problem in texture analyses. Under complete dispersion, textures of highly glauconitic soils seem predominantly clay, but under natural conditions the clay micelles are partially aggregated into sand-size particles that are dispersed only with difficulty. Hence results from texture analyses of these soils depend on the severity of dispersion techniques. In this study the apparent texture in natural soils seemed more important than true texture determined from complete dispersion, so samples of glauconitic soils were treated in the same manner as the others. The results indicate that the use of apparent texture was justified.

Values of table 2 should not be applied indiscriminately to soil series of the same name outside New Jersey. Even though the same name is used, the range in texture and other characteristics found within a soil series may be somewhat different for widely separated areas, particularly in the proportion of fine sand. Both the data of table 2 and the soil-factor equation are considered most applicable to New Jersey conditions.

Discussion

COMPARISON OF METHODS

Water-Table Measurements

For the most part the use of water-table data to predict site index seems impractical. Measurements would apparently have to be taken for several months, and data from one growing season would not usually be the same as those from another. Prediction of water-table depths and fluctuations by means of mottling or gleization patterns also seems impossible for the soils of this study. In certain soils the thickness of the mottled zone seemed to be correlated both with range in water-table depth and with site index. But in other soils slow internal drainage favored the development of mottling, while in still others no mottling was present even though the soils were quite wet. Gleization exhibited a similar lack of pattern for prediction purposes.

Such variation seems logical in view of present knowledge. According to the Russells (1954), mottling develops in sandy soils within the zone through which the water table fluctuates. Mottling is the result of alternate reduction and oxidation of iron and manganese. It does not develop below the dry-weather water table probably because little or no oxidation occurs, nor above the fluctuating wet zone because reduction does not occur. And, in some soils, iron and manganese are apparently present in too small amounts for mottling to develop even within the fluctuating water-table zone.

Soil Series vs. Soil-Factor Equation

For practical site-index predictions on some soils, either the soil series or the prediction equation seems adequate. However, within a soil series that has a wide range in site index, the equation approach will give more accurate estimates. Further investigation of these soil series may provide improved correlation of site index with mapping units or the subdivisions of each series.

Statistically, there are two reasons why the equation gives better estimates than soil series. First, the equation has a smaller error of estimate; and second, its estimate is for a specific area. In contrast, the average value for a soil series, as given in table 2, is from the several sampled areas considered representative of the particular soil. The extent to which the average and range in site index reflect the total variation possible is questionable, particularly for the soils with three or less samples. In addition, of course, there are areas with soils gradational between series.

Soil series have one advantage not shared by the equation. Where soil maps are available, the occurrence of sweetgum on similar soils can be determined more readily by the practicing forester.

The use of soil series for predicting site index has been criticized on the grounds that there is often as much variation in the site index within a soil series as between two soils. As table 2 shows, there is indeed appreciable variation within certain series, as well as overlap between series.

However, foresters and landowners should still find the data for soils series to be of value. For example, by knowing the location of a sweetgum stand or of a possible planting site for sweetgum, and by using a soils map and the information in table 2 of this paper, they might determine that the soil was mapped as a Weeksville fine sandy loam with a site index between 71 and 86. For greater accuracy, a field trip to check on the exact identification of the soil series or to obtain data for the soil-factor equation would be necessary.

APPLICATION

Soil series or soil mapping units have a big advantage in application wherever soil maps are available. However, the user of these maps should remember that:

- Soils are gradational, and different soil scientists may differ in their classification of intermediate soils;
- Where soil bodies are small, they may not be shown on soil maps because the scale limits the detail that is possible. And, under the usual standards followed in soil surveys, 15 percent of a mapping unit may be composed of inclusions of other soils.

- Soil classification has improved over the years, and as a result, series names have changed. Older soil maps were made under different standards and at different intensities than modern surveys. Users of soil maps should seek the most modern survey available or a modern interpretation of early surveys.

The most accurate identification of a soil is, of course, given by an experienced soil scientist examining a specific spot.

Application of the soil-factor equation can be done in one of two ways: (1) by measuring the thickness of the B_2 horizon and by estimating texture values, or (2) by measuring the thickness of the B_2 horizon and running a laboratory analysis of samples of the A and B_2 horizons. In both cases the thickness of the B_2 horizon *within the top 55 inches of soil only* is measured.

In both applications of the soil-factor equation, soils should be examined at several points or areas within a stand. If appreciable changes in texture and other characteristics occur, the different areas should be treated separately, unless the areas are so small they can be ignored. At each point considered, measurements or samples should be taken in at least three spots.

If the samples are to be analyzed in the laboratory, it is suggested that the soil from three auger borings be composited and, if time permits, that two such samples be obtained. A similar number of measurements of the B_2-horizon thickness should be made. The A horizon should be sampled in the surface 6 inches. Sampling of the B_2 horizon should start 2 inches below its top and extend for 6 inches or to the bottom of the B_2 (whichever is less). Laboratory analyses should be for (1) silt-plus-clay content of the A horizon, (2) silt-plus-clay content of the B_2 horizon, (3) fine-sand content, and (4) clay content of the B_2 horizon. In these analyses it is not necessary to remove the organic matter. However, the same procedure used in this study should be followed, especially the same rehydration period.

An approximation of site index can be made by measuring the thickness of the B_2 horizon and estimating texture by feel. The procedure is as follows:

1. By feel, place the B_2 horizon in one of 5 texture classes: (1) sand or loamy sand, (2) sandy loam or loam, (3) clay loams (including sandy and silty clay loams), (4) sandy clay, and (5) clay. Assume that the respective clay contents are 5, 15, 30, 40, and 50 percent.

2. Assume that the fine-sand content is 30 percent for most soils. Increase or decrease this figure for specific areas as experi-

ence indicates, and as ability to estimate fine-sand content improves.

3. Assume that the difference in silt-plus-clay content of the B_2 and A horizons is 5 percent.

4. Measure the thickness of the B_2 horizon (in top 55 inches of soil).

5. Use table 1 to estimate site index at several spots in the specific area, and obtain an average value. If differences are large, consider different portions of the area separately.

Errors in these approximations are, of course, introduced by the assumptions and by the method of determining texture class. In plastic soils there is a tendency to overestimate the amount of clay: for example, to classify clay loams as clays. This, of course, results in overestimates of site index. The assumption on fine-sand content will cause overestimates on some sites and underestimates on others, if the 30-percent value is used. Assuming a 5-percent difference in silt-plus-clay content of the B_2 and A horizons will not usually introduce an appreciable error; however, estimates may be too high for soils with sandy A horizons or those high in glauconite.

Of course, where it is feasible and not too much trouble, the use of two or more methods of estimating site index is preferable in an area. For example, if the regression equation (with texture analyses) is used along with the average value for soil series, the two methods should give a very good estimate of the potential productivity of the site for sweetgum.

MISCELLANEOUS OBSERVATIONS

Observations made during the study indicate that:

- Sweetgum appears to grow slowly on muck soils, the estimated site index there being 40 to 65 feet. However, this estimate is based on a limited number of observations.
- On muck or very wet mineral-soil sites, trees near ditches were taller than those farther away, probably because they were growing on material removed in ditch construction or maintenance. The resulting slight elevation above the surrounding land would give the sweetgum there a greater depth to free water.
- Except for the effect just mentioned, the influence of distance from ditches on site index was not discernible.

- Although sweetgum tends to be shallowly rooted on wet sites, windthrow is not common except near the edges of stands.
- The maximum site index measured for sweetgum in New Jersey is 95 feet, appreciably less than the 120 feet found by Broadfoot and Krinard (1959) in the South.

Summary and Conclusions

In the New Jersey Coastal Plain sixty-one 0.1-acre plots were established in sweetgum stands to determine relationships between site index and soil series, and site index and individual soil factors. The results indicate that site index can be obtained satisfactorily either from a soil-factor equation or from the mean value of a soil series. However, the site index of individual areas may differ somewhat from the predicted value, because of certain soil characteristics and water-table relationships that cannot readily be accounted for. For example, as yet there is no way of using soil-profile characteristics to indicate accurately the groundwater relationships.

For mature soils the important variables included in the final soil-factor equation for predicting site index are (1) percent of clay in the B_2 horizon, (2) percent of fine sand in that horizon, (3) the difference in silt-plus-clay contents between the B_2 and A horizons, and (4) the thickness of the B_2 horizon. Average depth to free water and fluctuations in this depth during the growing season are important water-table variables, especially in recent alluvial deposits.

Soil series are of value in site prediction, largely because subsoil textures are important both in soil classification and in their effect on the growth of sweetgum. The value of soil series in site prediction could be increased by mapping the relative thickness of subsoils (B_2 horizons), and by putting more emphasis on fine-sand content as opposed to total sand.

The results reported here are applicable only to the New Jersey Coastal Plain, and even there should be applied only to wet soils or to moderately well-drained soils of intermediate texture. Present plans are to extend this study to include Delaware and Maryland. It is expected that the additional data will improve both the sampling of soil series and the accuracy of regression estimates.

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Appendix

I

DESCRIPTION OF SOILS MOST FREQUENTLY SAMPLED

Adelphia loam

A horizon: 12 to 14 inches of dark grayish-brown, granular loam.
B horizon: olive-gray to yellowish-brown, somewhat blocky, sandy-cla loam, containing a moderate amount of glauconite.
C horizon: olive or olive-gray glauconitic parent material; more sandy and permeable than B horizon.
Distinct or prominent mottling below the brownish surface soil indicates moderately good to somewhat poor drainage. Water level[2] was at 12 to 24 inches between September and April, at 36 to 60 inches in July and August.

Bayboro loam

A horizon: 10 to 14 inches of black or very dark gray, granular loam.
B horizon: 10 to 16 inches of prominently mottled, gray, blocky clay or clay loam that is firm and plastic.
C horizon: prominently mottled, yellowish-brown or grayish-brown clay or clay loam.
Dark surface soil over a gray subsoil indicates very poor drainage.
Water level at an average depth of 6 inches between September and April; at 18 to 60 inches in July and August.

Bustleton loam (local name not correlated with national system)

A horizon: 6 to 10 inches of dark gray, granular loam.
B horizon: 10 to 30 inches of prominently mottled, yellowish-brown, blocky loam or clay loam that is firm and plastic.
C horizon: stratified; fine-sandy loam to clay layers; in places containing cemented ironstone.
Prominently mottled yellowish-brown subsoil and gray surface soil indicate poor drainage. Water level at 6 to 18 inches from September to April; at 30 to 60 inches in July and August.

Keansburg fine-sandy loam

A horizon: 6 to 14 inches of black or very dark gray, granular, fine-sandy loam.

[2] Water levels based on periodic measurements during 1 year at wells installed on the plots. Water levels mentioned are approximate averages for the periods and plots sampled.

B horizon: 12 to 18 inches of prominently mottled, gray to olive gray, somewhat blocky sandy loam.

C horizon: containing some glauconite, but sandier than B horizon.

Prominently mottled gray subsoil and dark surface soil indicate very poor drainage. Water level at 2 to 12 inches from September to April; 12 to 40 inches in July and August.

Matlock loam

A horizon: 12 to 16 inches of black or very dark gray, granular loam.

B horizon: 14 to 18 inches of prominently mottled, olive, blocky, sandy clay that is firm and plastic.

C horizon: sandier and more permeable than B horizon.

Although very poorly drained, these soils are not gray beneath the dark surface because the B and C horizons are highly glauconitic (olive colored). Water level at 2 inches from September to April; at 6 to 60 inches in July and August.

Othello loam

A horizon: 7 to 14 inches of dark gray, mottled, granular loam.

B horizon: 18 to 24 inches of prominently mottled, very dark gray, somewhat blocky loam or silt loam that is firm and plastic.

C horizon: sandier than B horizon; generally stratified, in places with gravel.

Gray surface over gray subsoil indicates poor drainage.

Rancocas fine-sandy loam (local name not correlated with national system)

A horizon: 6 to 10 inches of black to very dark brown, granular, fine-sandy loam.

B horizon: 16 to 26 inches of prominently mottled, dark gray or very dark gray, somewhat blocky to blocky, loam to clay loam that ranges from friable to firm and plastic.

C horizon: stratified, granular layers of fine sand to sandy clay, mostly olive colored.

Soils are considered very poorly drained. Water level at 6 inches from September to April; at 30 to 40 inches in July and August.

Weeksville fine-sandy loam

A horizon: 14 to 16 inches of black or very dark gray, granular, fine-sandy loam.

B horizon: prominently mottled, gray or grayish-brown, somewhat blocky, friable, fine-sandy loam.

C horizon: usually below 40 inches; a friable, gray, loamy fine sand. Sand is predominantly and uniformly fine.

Drainage considered to be very poor; water level at 2 inches from September to April, and at 36 to 48 inches in July and August.

II

DATA FROM SOIL-TEXTURE ANALYSES

To supplement the above soil descriptions, average data from the texture analyses of each soil series are given below (table 3). The usual sampling methods are described in the text. However, it should be noted here that in recent alluvial deposits samples of the B_2 horizon were arbitrarily taken from the 10- to 20-inch depth.

Table 3. — *Average data for soil series, from texture analysis*

Soil series	Silt-plus-clay content of A horizon	B_2 horizon		
		Fine-sand content	Silt content	Clay content
	Percent	*Percent*	*Percent*	*Percent*
Klej	11	41	7	4
Rutlege	9	25	6	3
Nixonton	20	42	5	21
Dragston	15	18	11	9
Fallsington	16	23	21	10
Pasquotank	14	49	5	10
Keansburg	26	48	16	22
Weeksville	28	51	15	22
Pocomoke	12	24	16	10
Collington	10	35	2	21
Mattapex	45	31	22	23
Adelphia	42	31	22	27
Bustleton	55	33	33	24
Othello	53	27	37	25
Rancocas	41	33	23	29
Bayboro	38	30	17	35
Colemantown	58	21	15	52
Matlock	31	22	10	37
Glauconitic alluvium	22	53	13	15
Non-glauconitic alluvium	14	26	7	8

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