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RESEARCH PAPER

Site quality evaluation of loblolly pine on the South Carolina Lower Coastal Plain, USA

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Abstract: Eleven soil types, which can be identified and delineated using conventional soil survey procedures, were characterized for loblolly pine (*Pinus taeda* L.) productivity. Four 4-hectare study sites, each containing four measurement plots, were established for every soil type studied. In a stepwise multiple regression, both soil parent material (i.e. a combination of subsoil texture and geology) ($p<0.001$), and drainage class ($p=0.006$) were significant predictors of site index (tree age 25), and the overall linear regression model had an R^2 value of 0.55. The extremes of soil parent material differed by 3.9 m site index (loamy subsoil on the Wicomico-Penholoway surfaces versus clayey subsoil on the Pamlico-Princess Anne surfaces). Each increment of drainage class differed by 0.7 m site index. For example, a poorly drained soil had 0.7 m lower site index than a somewhat poorly drained soil. For seven of the eleven soil types studied, there is greater than 80% probability that estimated mean site index is within ±0.8 m of the actual soil type mean site index. The other four soil types (labeled G, I, C and K) need to be either redefined or sampled more intensively. Two of these need to be subdivided in order to adequately characterize site quality, one based on geology (Soil type G) and one based on soil drainage class (Soil type I). Variation in soil drainage class and varying amounts of topsoil displaced into windrows were both factors influencing site quality variation of a third soil type (Soil type C). The wide variation in site index data for a fourth soil type (Soil type K) appeared to be due, in part, to sampling study locations and individual measurement plots with less than optimum bedding and/or artificial drainage. Soil parent material (subsoil texture and geology) along with drainage class were found to be important factors influencing site quality on the South Carolina Lower Coastal Plain.

Keywords: site index; geology; soil parent material; soil texture; drainage class

Introduction

The practice of site-specific intensive forestry requires that practitioners first be able to identify and classify sites. Individual site types must be characterized as to operability, response to cultural practices and potential productivity. Once a site classification system is in place, it can facilitate both current management decision-making and development of new technology. Research can be oriented toward site-specific problems and opportunities. Technology transfer is simplified because new research results are incorporated into the site classification system as a part of individual site type descriptions.

Forest site quality evaluation studies have two objectives. The first is to characterize potential site productivity under a specified management regime; the second is to identify associations between soil-site features and tree growth. Working hypotheses about how environmental factors influence productivity are formulated as a result. These hypotheses may then become the basis for future site-specific silvicultural research and/or forest soil mapping.

Numerous soil-site studies have been conducted on the Coastal Plain of the United States. Carmean (1975) summarized results published prior to the early 1970's. In the 1950's, Auten produced soil-site tables applicable to MeadWestvaco's South Carolina Coastal Plain properties. More recently, Campbell (1978) described site index prediction equations developed by Weyerhaeuser for eastern North Carolina. In the 1970's Smith reported data collected by the Natural Resources Conservation Service (NRCS) for the South Carolina Coastal Plain. The US Forest Service has produced a model for predicting site index throughout the Coastal Plain (Harrington 1991).

Coastal Plain soil-site studies dealing with pine species identified climatic, topographic and soil features correlated with tree growth (Carmean 1975; Harrington 1991). In studies where a wide range of climatic conditions were included, rainfall, latitude and temperature were most important. Studies on parts of the Coastal Plain where topographic features are more pronounced have recognized the effects of slope position and slope steepness

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on site quality. Soil features which have been identified to predict site index can be grouped into four categories: soil drainage, surface soil depth, surface soil properties and subsoil properties (Campbell 1978; Carmean 1975; Harrington 1991; McKee 1977).

Aspects of soil drainage associated with site quality on the Coastal Plain include both surface drainage and internal drainage as indicated by soil drainage class or depth to mottling. Surface soil depth has been characterized in several ways. Different researchers have identified A1 horizon depth, A horizon depth, depth to fine textured horizon and depth to least permeable horizon as important parameters. Surface soil texture and organic matter content were correlated with site quality in a few cases, while subsoil properties such as texture (B and C horizons), plasticity, pH and the presence of phosphate marl have more frequently been reported as important (Campbell 1978; Carmean 1975; Ellerbe et al. 1963; Harrington 1991; McKee 1977).

McKee (1977) evaluated the variation in soil properties within three Lower Coastal Plain soil series. Multiple regression equations relating site index to soil physical and chemical properties for the three soil series had R^2 values of 0.60, 0.65 and 0.74. Variables used in one or more of the equations included nitrogen, phosphorus, calcium, pH, and percentage of sand and clay in the A1 or B2 horizons. A regression equation developed using combined data from all three series had an R^2 value of only 0.22. McKee attributed differences in the regressions for individual soil series to differences in soil drainage class.

Campbell (1978) reported that inclusion of information on landform class (pocosins, flats, clay uplands or sand uplands) greatly improved Weyerhaeuser’s soil-site equations. Separate regression equations developed for each landform class utilized different variables in combination with soil drainage class to predict site index, and required fewer variables than the general equation.

A wealth of information has been published on the geology of the South Carolina Lower Coastal Plain (Cooke 1936; Colquhoun et al. 1983; McCartan et al. 1984). Most of the soils are derived from Quaternary marine and fluvial sediments. Five depositional environments are recognized: deltaic plains, barrier island and bar hills, shelf plains, marsh plains and valley systems (Colquhoun 1969, 1974). Soils formed in former marsh plains are the most productive while soils formed in old barrier islands and bar hills are generally the least productive.

Post-depositional weathering is also a factor influencing forest site quality. Sediments found further inland at relatively high elevations on the Wicomico (24–34 m) and Penholoway (13–24 m) Terraces are considerably older than the Talbot (8–13 m), Pamlico (4–8 m) and Princess Anne (2–4 m) Terraces, which are located nearer to the coast. Soils derived from older sediments tend to be acid and infertile due to weathering, regardless of the original character of the sediment. Soils derived from young sediments are more likely to be fertile. Analogous relationships can be observed within a terrace where elevation and landscape position result in hilltops being much less fertile than depressions and drainage ways.

Where Quaternary surface deposits are thin, the older sediments of Tertiary age influence soil properties. Deposits of phosphate rock are associated with the base of the Quaternary sediments, particularly where those sediments are in contact with the top of the Cooper Marl. The phosphate rock was formed when phosphate in sea water replaced carbonate in the marl (Malde 1959). Morphologically similar soils have been shown to differ greatly with respect to site quality depending on whether or not phosphate rock was present at shallow depth (Ellerbe et al. 1963).

Stone (1978) criticized traditional soil-site studies noting that, “the products of these studies were graphs and equations whereas the tools for forest planning and management are maps and inventories. Thus the results really had limited application except when they had been coupled to existing maps or used to guide new mapping. Such coupling, however, then entailed the realities of landscape variability, the limitations of map scale, and the human difficulties in mapping, all of which had been nicely avoided in data obtained from selected small plots.”

MeadWestvaco’s approach to site quality evaluation included the soil survey process. We (the authors) studied soil types which can be identified and delineated using soil mapping procedures. The lines drawn on a map by a soil surveyor define areas of contrasting soils. A single polygon thus created is defined as a map unit delineation. Soil type (also referred to as a soil mapping unit) is a term describing all similar map unit delineations, comprised of soils with similar properties and similar management interpretations. When mapped across the landscape, a soil type occurs repeatedly in a predictable pattern corresponding to natural topography and local geology. The purpose of our study was to characterize loblolly pine (*Pinus taeda* L.) productivity for selected soil types on the South Carolina Lower Coastal Plain, and to determine the accuracy and homogeneity of site index estimates for soil types.

Materials and methods

Establishment of this study preceded operational land classification mapping of MeadWestvaco’s property on the South Carolina Lower Coastal Plain. The soil types described in this report were prototypes, which tended to be more broadly defined than MeadWestvaco’s operational soil types. Factors considered in map unit definitions included site quality as well as wet-weather trafficability for logging equipment, compaction potential (during wet conditions), silvicultural drainage, site preparation techniques including herbicide recommendations, and fertilization recommendations. Soil map units with similar site quality can differ in one or more other management interpretations.

A total of 218 loblolly pine plantations planted before 1975 were identified as possible study sites. The stand selection criteria included: (1) not superior genetic stock, (2) bedded, (3) phosphorus fertilized at planting if judged deficient based on soil test (standard practice at the time for MeadWestvaco), (4) adequate artificial drainage, (5) not thinned, (6) not fertilized at midrotation with nitrogen (midrotation nitrogen fertilization was an uncommon practice for MeadWestvaco in the 1980s), (7) not burned so hot as to damage trees and (8) relatively large acreage included within a single map unit delineation (4 to 20 hectares).

Eleven soil types were selected for initial plot establishment between 1985 and 1987. Soil types were chosen to represent a substantial percentage of MeadWestvaco acreage, a wide range of site indexes, and a variety of drainage classes. Some soil types were chosen because they were found together in the same catena. Each soil type had four or more suitable loblolly pine stands. When more than four stands were available, four were chosen at random. A soil map of each pine stand was drawn, and a 4-hectare study area was randomly located within single map unit delineation. Four 0.04-ha permanent measurement plots were then randomly placed within each 4-hectare study location. Measurement plots were not placed on windrows, within 40 m (two chains) of a major ditch, within 20 m (one chain) of a road nor within 10 m (one-half chain) of a soil map unit boundary. For each soil type studied, 16 plots were established (4 locations, 4 plots per location).

A brief soil description was made from an auger boring and soil samples collected by horizon at each measurement plot. Each horizon was described by name, depth, percentage drainage mottles and texture. Drainage class and depth to gray matrix were also described for each profile. The five most abundant species of understory vegetation were listed and any root mat present described. If the soil was considered to be a contrasting or similar inclusion within the map unit, that fact was noted.

Height, diameter at breast height, and crown class were measured for all trees on each plot. Eighty plots were established during the winter dormant season from 1985 to 1986, and 96 plots were established during the winter dormant season from 1986 to 1987. The plots that remained in good condition were subsequently remeasured every three years. Hurricane Hugo severely damaged all plots at 24 of the 44 study locations in 1989; these locations were dropped from further study. Final measurements used in this report were collected at the following stand ages: 60 plots at 14 to 16 years old, 40 plots at 18 to 20 years old, and 76 plots at 21 to 25 years old. Site index was calculated using the average height of all planted dominant and codominant trees on each plot, and site index curves of Clutter and Lenhart (1968). The index age for these site index curves is 25 years, i.e. all height-age data was projected to tree age 25.

Two stepwise multiple regression analyses were conducted. Location mean site indices (Table 3) were used in both these analyses (N=44). The first analysis tested the relationship of site index with surface geology, subsoil texture, and drainage class. The second regression analysis evaluated the relationship of site index with soil parent material and drainage class. Surface geology was defined as a three level variable with numeric values assigned to the levels as follows: (1) Wicomico and Penholoway surfaces, (2) Talbot surface, (3) Pamlico and Princess Anne surfaces. Subsoil texture was defined as: (1) Loamy and (2) Clayey. Drainage class of the soil type was defined as a numeric variable ranging from: (1) Moderately Well Drained to (4) Very Poorly Drained. Soil parent material was a fertility indicator defined by a combination of surface geology and subsoil texture. The soil parent material variable was determined by the following equation and ranged from 2 to 3.67:

$$S=S_t/G+G \qquad (1)$$

where, S is the soil parent material, S_t the subsoil texture, and G is the geology.

This equation gives more weight to differences in texture on the older surfaces and indicates that texture has less of an effect on fertility on the younger surfaces. All variables had to be significant at the 0.15 level to be entered into the stepwise regressions and significant at the 0.05 level to be retained.

Mean site index, the standard error, and the probability associated with a ±0.8 m (±2.5 ft) confidence interval, were calculated for each soil type. Soil types were considered to be accurate predictors of site index if there was an 80% probability that a sample mean site index was within ± 0.8 m (±2.5 ft) of the true mean site index. This level of accuracy was considered satisfactory for operational management decision-making. Variation among soil types and within soil types was evaluated by analyses of variance (ANOVA) and Student-Newman-Keuls' multiple range test.

Results

Characteristics of the soil types in this study are summarized in Table 1. Soil type drainage class (internal drainage) ranges from moderately well drained to very poorly drained, with eight of the eleven soil types classified as either somewhat poorly drained or poorly drained. Four soil types have sandy textured surface soil horizons and loamy subsoil horizons, while seven soil types have loamy or clayey surfaces and clayey subsoil.

Soil drainage class is largely a function of landscape position. Moderately well drained Soil type H is found on knolls and dry edges adjacent to drainage ways. Somewhat poorly drained soil types occupy slightly elevated landscape positions on nearly level flats (Soil type A), nearly level ridges (Soil type I) and irregular ridges (Soil types D and J). Poorly drained soil types occur at lower elevations in broad depressions or flats (Soil types B, C, F and G), while very poorly drained Soil types E and K are found in depressions and at the heads of natural drainage ways.

Soil texture is related to the environment in which the parent material was deposited. Coarse textured parent materials are deposited in high energy aquatic environments, while clays are deposited in relatively calm waters. Soil types with sandy textured surface soil and loamy subsoil are derived from fluvial (Soil type H), barrier island (Soil types C and I) and offshore deposits (Soil type A). Soil types with clayey textured subsoil are formed from backbarrier (Soil types B, D, F, G and J) and estuarine deposits (Soil types E and K).

Seven of the 11 soil types are influenced by the presence of underlying, more fertile, marine sediments at shallow depth. Soil types derived, in part, from the Tertiary deposits tend to be less acid and more fertile, with more base cations and more phosphorus than morphologically similar soil types derived exclusively from younger Quaternary sediments. In the field, soil fertility can often be inferred from the composition of the understory plant community. Indicators of fertile sites include devil's walking stick, dwarf palmetto, American hornbeam, winged elm, swamp chestnut oak, American beech and spruce pine.

Table 1. Properties of the soil types studied

Soil type	Similar soil series	Drainage class	Texture (Surface/Subsoil)	Landscape position	Parent material	Influence of marl[1]
A	Lynchburg	Somewhat Poorly Drained	Sandy/Loamy	Slightly-elevated nearly level flats	Offshore deposits of Penholoway surface	None
B	Meggett	Poorly Drained	Clayey/Clayey	Broad depressions	Offshore deposits of Penholoway surface	Slight
C	Pelham	Poorly Drained	Sandy/Loamy	Nearly level flats	Barrier island deposits of Penholoway surface	None
D	Wahee	Somewhat Poorly Drained	Loamy/Clayey	Slightly-elevated irregular ridges	Backbarrier deposits of Talbot surface	None
E	Cape Fear	Very Poorly Drained	Clayey/Clayey	Broad depressions and heads of drains	Estuarine deposits of lower Talbot surface	Slight
F	Argent, Mouzon, Meggett	Poorly Drained	Clayey/Clayey	Broad flats	Backbarrier deposits of Pamlico-Princess Anne surfaces	Strong
G	Bladen	Poorly Drained	Loamy/Clayey	Broad flats	Backbarrier deposits of Talbot and Pamlico surfaces	None[2]
H	Hockley, Yauhannah	Moderately Well Drained	Sandy/Loamy	Knolls and dry edges next to drains	Fluvial deposits of lower Talbot surface	Slight
I	Albany	Somewhat Poorly Drained	Sandy/Loamy	Slightly-elevated nearly level ridges	Barrier island deposits of Wicomico surface	None
J	Okeetee, Wahee, Craven	Somewhat Poorly Drained	Loamy/Clayey	Slightly-elevated irregular ridges	Backbarrier deposits of Pamlico surface	Moderate
K	Brookman, Santee	Very Poorly Drained	Clayey/Clayey	Depressions and heads of drains	Estuarine deposits of Pamlico-Princess Anne surfaces	Strong

Notes: [1] Influence of marl or other Tertiary age sediments on soil chemical properties; [2] Slight influences on Pamlico surface, none on Talbot.

In the first stepwise multiple regression analysis, which tested geology, subsoil texture and drainage class, only geology was related to site index ($p<0.001$, $R^2 = 0.38$). The difference in site index between the Wicomico-Penholoway surfaces, and the Pamlico-Princess Anne surfaces was 2.8 m in this regression. In the second stepwise regression analysis, both soil parent material ($p<0.001$) and drainage class ($p=0.006$) were significant predictors of site index and the overall regression model had an $R^2 = 0.55$. The extremes of soil parent material differed by 3.9 m of site index (loamy subsoil on the Wicomico-Penholoway surfaces versus clayey subsoil on the Pamlico-Princess Anne surfaces). Each increment of drainage class differed by 0.7 m of site index. For example, a poorly drained soil had 0.7 m less site index than a somewhat poorly drained soil.

Mean site indices for these soil types spanned the range from 19.6 m for Soil type C to 25.3 m for Soil type J (Table 2). The site indices for many soil types were found not to be significantly different from one another ($\alpha=0.05$). The results of this study do show that soil type mean site index can be accurately estimated for a majority of the soil types. For seven of the eleven soil types there was greater than 80% probability ($\alpha=0.20$) that estimated mean site index (age 25) was within ±0.8 m (±2.5 ft) of the actual population mean site index.

Results obtained for four of the soil types were unsatisfactory for various reasons. Soil type C appeared to be inherently more variable with respect to site quality than most soil types. Soil type C has light root mat present and is sensitive to topsoil displacement. Variation in soil drainage class and varying amounts of topsoil displaced into windrows were both factors influencing site quality on Soil type C.

Table 2. Mean site indices of soil types

Soil type	Mean (m)[1]	Standard error (m)[1]	±0.8 m CI probability (%)[2]
J	25.3a	0.4	80
Gb[3]	24.8ab	0.8	50
K[4]	24.3abc	0.6	60
F	24.3abc	0.4	80
H	24.2abc	0.4	80
B	24.2abc	0.2	95
E	22.8bcd	0.4	80
I	22.5cd	0.7	60
D	21.8d	0.2	95
Ga[3]	21.4d	0.6	50
A	21.0de	0.3	90
C	19.6e	0.6	60

Notes: [1] Mean site index of soil type: the same letter means no significantly different at $p<0.05$; [2]Probability that estimated soil type mean site index is with ±0.8 m (±2.5 ft) of the population mean; [3]Data for Soil type G subdivided into two groups. Ga: study locations on the Talbot Surface and Gb: study locations on the Pamlico Surface; [4]Analysis of Soil type K excludes data for two plots which appeared ponded. Site indices for these two plots on Soil type K were 18.6 and 19.2.

Results obtained for Soil type G also proved to be unsatisfactory because morphologically similar soils found on the Pamlico and Talbot Surfaces differ in fertility and productivity. The two study locations on the Pamlico Surface had a higher site index (Table 2, Soil type Gb) than the two study locations on the older, more weathered, Talbot Surface (Table 2, Soil type Ga). Soil type I proved to be too variable with respect to site quality and soil drainage class. While the soil type was defined as somewhat poorly drained, one of the four study locations was classified as poorly drained. The poorly drained study location had higher site indices than the other three locations (Table 3).

Variation in site index observed on Soil type K appears to be due, in part, to variation in management. Internal soil drainage for Soil type K is very poor; hence artificial drainage and bedding are critical for pine survival and growth. Uniformly high site indices were observed at one study location which clearly benefited from successful artificial drainage. However, two other study locations showed the effects of excess water and sub-optimal plantation establishment and 2 plots (one from each location) were dropped from the analysis. The fourth study location had intermediate site indices.

Table 3. Mean site indices in studied locations

Soil type	Location			
	1	2	3	4
A	20.4a[1]	20.7a	21.0a	21.8a
B	23.7a	23.9a	24.4a	24.6a
C	18.3a	19.2a	19.4a	21.4a
D	21.5a	21.6a	21.7a	22.3a
E	21.6a	22.9b	23.2b	23.3b
F	23.5a	24.2a	24.3a	25.2a
G	20.7a	22.0a	24.1b	25.6c
H	23.1a	24.5b	24.6b	24.8b
I	20.8a	22.1ab	22.9bc	24.4c
J	24.4a	25.2a	25.4a	26.4b
K[2]	23.6a	23.6a	23.9a	26.2b

Notes: [1] Within a soil type, location means followed by the same letter are not significantly different at $p<0.05$; [2] Analysis of Soil type K excludes data for two plots which appeared ponded. Site indices for these two plots on Soil type K were 18.6 and 19.2.

The problems in evaluating Soil types C, G, I and K, simultaneously highlight strengths and weaknesses of this study. Stand selection criteria and rules for measurement plot placement were kept to a minimum so as not to introduce bias. This approach characterized site quality under typical pre-1975 "best management practices" rather than "optimum" conditions. In the case of Soil type K, inclusion of study locations and individual measurement plots with less than optimum bedding and/or artificial drainage made the data set quite variable. Soil types E, H and J each had one location which differed significantly in site index from the other three locations (Table 3). For these three soil types, variation within a location was quite small compared to variation among locations. Even so, there was still greater than 80% probability that the soil type site index means were within ±0.8 m (±2.5 ft) of the true site index means.

Conclusions

Mean site indices can be accurately estimated for a majority of the soil types studied. For seven of the eleven soil types, there was greater than 80% probability that estimated mean site index at age 25 was within ±0.8 m (±2.5 ft) of the actual population mean. Soil parent material and drainage class were important factors influencing soil-site relationships in this study. The most productive soils were those found at 2 to 8 m above sea level on the Pamlico and Princess Anne Surfaces. Site quality decreased progressively as one moved inland. Soil types found on the Talbot Surface (at elevations of 8−13 m) were intermediate in site quality, and loamy soils of the Penholoway Surface (at elevations of 13−24 m) were more weathered, less fertile and less productive than the clayey soils of the Talbot, Pamlico or Princess Anne Surfaces. Drainage class modified these relationships regardless of the soil parent material, with better drained soils being more productive than less well drained soils.

This study represents MeadWestvaco's forest management in 1969−1974. Management at that time differs from current practice in several ways. Planting genetically improved stock or clones, and the use of herbicides at establishment (Allen et al. 2005) have resulted in improvement in site quality across many of the soil types included in our study. The use of repeated N and P fertilizations of established stands may also raise the site index of the relatively infertile soil types. The challenge now is to model changes in site index by soil type that are due to changes in management practices. When a land classification system is well done it should be sufficiently robust to accommodate changes in management and new soil type interpretations.

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