RELATIONSHIPS OF SOIL, FOLIAR AND TOPOGRAPHICAL CONDITIONS TO SYCAMORE GROWTH IN A 47-ACRE PLANTATION

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Thesis for Master of Science in Fore[stry]

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TABLE OF CONTENTS

I. Problem

A. Introduction

1. Purpose of the Study

Because of certain unique pulp traits, pulp and paper mills desire hardwoods for the production of many "high quality" materials. In many localities, the hardwood resource is insufficient and of poor quality. Much of the hardwood timber is located on lands which are inaccessible during much of the year. Timber on these lands is expensive to log and to process. Stud ies, such as this one that help describe productive hardwood lands which are easily accessible, will aid in management decisions.

American Sycamore (Platanus occidentalis L.) is a hardwood tree species w ith a good growth rate under the proper environmental conditions. However, like most hardwoods, it is site specific-requiring a somewhat narrow niche for fast growth. The major emphasis of this study is to determine the range and characteristics of this niche for the study location.

Many reports have emphasized the importance of the condition of the site to the productivity of hardwoods. Both the physical and chemical soil properties have been related to hardwood growth with soil moisture and soil fertility being the most commonly mentioned critical properties. This study attempts to quantify some of these relationships for Sycamore growing on a previously considered "non-hardwood" site.

2. Hypotheses formulated

On the basis of previous studies, it was hypothesized that Sycamore growth would be better on the moist, loamy and more fertile sectors of the study area.

For optimum growth, it was also thought that the top six inches of soil should display a rela tively high organic matter content coupled with a low clay content. If previous findings are followed, the best plots will be slightly depressed on t he landscape, while the upper ridges will portray the worst Sycamore growth. In general, basic soil cations, soil phosphorous levels, nutrient foliage concentrations, and water holding capacities are thought to positively correlate with sycamore growth while hydrogen and aluminum concentrations, soil strength and bulk density often negatively correlate with the performance of this species.

B. Review of previous research

Native hardwoods are the principal timber type on more than 1000,000 acres of Southern forest land. Even on fertile sites, native hardwood growth is disappointing because of past abuse and extremely overstocked conditions. For this reason, intensive hardwood plantation management is being employed in order to significantly increase hardwood pulp productin per unit time. On the proper site under intensive plantation management, Sycamore will grow to pole-sized (3-10 inch diameter) timber in ten to twelve years. Hardwoods, such as sycamore, even pe rform well on some upland sites if the site receives proper site prepara tion and fertilization.

With a dequate competition control, the initial grow th of sycamore is good on most for est sites; however, on many sites, the growth rate dramatically decreases after the first couple of years.(63) It is therefore imperative to wait until the sycamore trees are at least six to seven years old (more than half their rotation length) before measuring them as an index of site pro ductivity.

The sycamore wood produced by this short rotation approach is of high quality. It has goo d burst, tear and fold properties,and it will produce a high quality paper. Juvenile sycamore wood has been found to be up to 7% less dense tha n mature wood of the same species; however, excellent pulp yields per unit area still exist on suitable sites.(61) Mature sycamore wood has an average specif ic gravity of .46 yielding 28.7 pounds of dry fiber per cubic foot. Its green moisture content is estimated at 121%. (63) These figures represent an ample production of quality wood.

Even though proper site selection is important, optimum utilization of the plantation site is just as critical. Establishment costs for hardwood pla ntations are expensive, ranging from $75.00 to $125.00 per acre on most s ites. In general, hardwood establishment costs would be about $25.00 per acre greater than the costs to establish a pine plantation on the same site.(197) However, on the best sites, syc amore will produce more wood volume than pine during a short rotation (10-15 years). Therefore, for industriesdesiring hardwood fiber, sycamore plantations are an attractive investment on highly p roductive sites.(197)

The me thod of site preparation for hardwood plantations varies considerably depending on the site's condition and the industry involved. The objective, however, remains the same; to present the genetically improved stock with a "clean", fertile, loose and moist location in which to grow. In general, the more elaborate the site preparation, the more growth that will result; however, expenses also increase.(31) A necessity in any hardwood site preparation effort is to work on an area which has undergone a clean clearcut. This involves cutting the unmerchantable as well as the merchantable trees. This is followed by root-raking, piling and then removal of the piles (by burning or by moving them along the field's borders to deter deer). Disking and, if necessary, bedding are done just before planting. Fertilizer applications, preferably as recommended by soil tests, can bemade prior to planting, during the planting process, and after planting. Liming should be done a couple of months before planting, in order to allow it to react in the soil. One of the most complex pieces of planting equipment first beds, then subsoils, deposits fertilizer in the resulting trench and finally plants the tree in the same operation across the field. This obviously saves considerable time over doing each procedure separately.

The quality of the planting stock is just as important as intensive site preparation. Genetically improved one-year old, root-pruned sycamore seedlings should be used. The root collar diameters of the seedlings seem to have high positive correlations with growth potentials.(601) (602) In a Georgian study, first-year plantation height growth of 1-0 Sycamore seedlings averaged more than six feet for seedlings of more than 0.5" root collar diameter; however, those seedlings with root collar diameters less than 0.3" only averaged two and sixth tenths feet of height growth in the same amount of time.(63)

Usually, the initial spacing is arranged so that no thinning will be required during the short rotation. Spacing is dependent upon the size of timber which the company wants to handle and the cultivation control which it is willing to perform. If a company is only interested in harvesting trees greater than 5" in diameter, then at least an 8' x 9' spacing is recommended.(75) However, if no cultivations are performed on the site and if the company can use smaller timber, then smaller spacings such as 6' x 6' should be used to deter "weed" competition.(53)

Fertilization is required for most sycamore plantations-particularly those established on the upland. Operationally, only nitrogen and phosphorous, along with liming agents, have been used to any marked extent. Chemical soil tests can help advise the manager as to how much lime, nitrogen and phosphorous that hsi land needs. It can also point out severe deficiencies in other nutrients.

Several studies illustrate that fertilizers often increase growth of plantation hardwoods. Nitrogen fertilization was found to increase cottonwood growth on alluvial, agriculturally degraded soils.(7) In addition, cottonwood was stimulated by fertilizer treatments to other terrace and bottom soils of low natural fertility.(27) Fertilizer additions also showed considerable potential for increasing yellow poplar growth on eroded, silty uplands; however, maximum growth would have required an increase in soil moisture.(11) (27) In many instances, even on upland sites, hardwoods perform well after they have been stimulated by fertilizers and liming agents. Usually, the trees have the greatest response to nitrogen additions.(28)

Sycamore, like other hardwoods, responds well to fertilizer additions. In a study performed on the flood plain of the Oconee River in Georgia, nitrogen fertilization statistically increased sycamore's height growth over that of the check.(27) In another study, fertiliser was found to nearly double sycamore growth; in addition, properly prepared and fertilized sycamore seedlings were able to outgrow weeds that often defeat old-field pine plantations in the study area.(34)

Proper fertilis ation procedures involving banded applications of the right ferti lizer at the proper time is very important. Until after crown closure, all fertilizer applications, except for lime, should be placed along a ban (bedding, banding, or in the planting hole) in line with the crop trees.(20) If weathe r or terrain detours banding operations after plan ting, then broadcast nitrogen applications should be postponed until after crown closure, so that weed competition will not be encouraged.(26)

If the site requires fertilization, then a sensible fertilising schedule should be developed. Union Camp has developed a rough fertiliser guideline for hardwood plantations. At planting, they propose adding .20 pounds of ammonium nitrate per tree if the site is not low in phosphorous; if the site shows phosphorous deficiency then .35 pounds of diammonium phosphate should be used per seedling. This application is followed by a banded treatment of fifty pounds of nitrogen per acre at the beginning of the third year (if the phosphorous level is low then diammonium phosphate is used). At age seven or eight (after crown closure), another fifty pounds per acre of nitrogen is broadcasted over the site.(1) Kellison thinks that the high mobility of nitrogen requires more frequent applications- at least every two years The lighter the soil, the more frequent the applications will need to be spaced; however, less fertiliser will need to be applied to the sandier soils at a given time. In general, the ammonium form of nitrogen has been found to be superior to the sodium form of the same nutrient. This mainly seems to be due to slower losses of nitrogen when the ammonium fertiliser form is used.(63)

Another important post-planting operation is cultivation. Disk cultivation should be performed as often as necessary throughout the first growing season. Often, cultivations are also required during the second year. Two-way cultivation is obviously the most effective. If the extra trips over the field can not be warranted, then alternating the direction of each suceeding cultivation is helpful.(166) In order to receive good sycamore growth even on the best sites, intensive site preparation and cultural treatment must be employed.

Despite good cultural treatment and site preparation, sycamore still requires high quality land in order to grow at acceptable rates. It is a major purpose of this thesis to quantify some of the constituent parts of this high quality environment.

Topography is one major constituent of any environmental system. The topographical position of a site is a major factor in determining the site's soil properties. It strongly affects the moisture, textural and chemical characteristics of the soil. The topographical position has been found to be a major factor in determining the site index.(21) (54) (68) In general, the most productive microsite has been found to be a depressional pocket, a slough, a dip, a swag, or a concave surface.(54) This type of an area allows for moisture and nutrient accumulation; in addition, slow-moving water is sometimes ponded on these areas thus allowing fertile, fine-sized sediment to settle out in these regions. Especially in low-lying areas, very small changes in elevation can cause very large site index changes.

Soil moisture is often highly correlated with topography. Other factors, such as climate, soil texture, soil structure and the density of the stand are also instrumental in explaining water availability. Yellow poplar's growth, like that of other hardwoods, has been found to be largely moisture dependent. Shipman's thesis found that the soil moisture regime throughout the growing season was the major limiting factor contributing to the substantial differential height growth of plantation grown yellow poplar.(16) Sycamore prefers well-drained moist soils. It has been found that sycamore grows best under a soil moisture equivalent (field capacity) regime. Deviating the soil moisture (either increasing or decreasing it) from this optimum level causes a decrease in the overall nutrient uptake of sycamore.(4) (67) Water and nutrients are still taken up by sycamore down to its wilting point, even though this uptake occurs at a progressively slower rate as soil moisture tension increases. Therefore, the available water capacity of the soil (the amount of water held between the wilting point and field capacity), along with the initial moisture level, largely determines a soil's drought resistance capability.

Broadfoot found that the major cause of dieback from southern hardwoods is insufficient soil moisture. On the average, five feet of sandy soil can only hold a fifteen to twenty day water supply for a fully stocked timber stand. However, siltier soils, such as silt loams, can store three times more water in the same depth of soil. Therefore, soil texture is a major factor in determining water storage capacity.(362)

Soil textur e throughout the soil profile is strongly related to hardwood growth. It is a major factor in many hardwood site index equations.(21) (91) (92) (93) Sycamore growth is also strongly related to soil texture. Sycamore prefers light soils (51), with sandy loam, silt loam or loam as its optimum soil textures). Studies have shown that loamy soils are preferred by most valuable hardwood species.(54) (14)

The aggregation of the individual soil particles, soil structure, is important in optimizing soil strength, moisture and air interrelationships. Organic matter and biological activity are very important in encouraging good, stable and friable structure. A good structural relationship provides a meshing of macropores and micropores so that water, air and roots interrelate properly within the soil.

Soil structure, along with soil moisture and soil texture, strongly affects soil strength. Trees desire soil systems which are s trong enough to support their growth but yet allow easy root penetration. Naturally strong soils, such as clays, require good structure that provides adequate macropores for root penetration and air space. Large voids can allow root penetration through otherwise impervious soils, such as very heavy clays or hardpan units. On the other hand, naturally weak soils, such as sands, require substantial "consolidation" of material for added strength and to entrap scarce water and nutrients.

Usually, decreasing the moisture in a given, unsaturated soil, increases its stength. As the soil moisture tension substantially builds, root penetrability decreases.(40) Thus, high soil strength and soil moisture tension work in tandem, decreasing the ability of the roots to "reach" nutrients and moisture.

General soil profile characteristics are also indicative of hardwood site quality. In general, hardwoods prefer deep, non-restrictive soils. Recently deposited and young soils are preferred over those soils with extensive profile development.(54) (14) Inaddition, bright colored (black, brown or red) soils usually indicate better water-air relations for ha rdwoods than do duller, gray soils.(54) This is partically true for sycamore which grows best under well-drained conditiions.

Chemical soil properties are also very critical in hardwood management. Hardwoods, in general, a nd sycamore, in particular, prefer the soil reaction to be about neutral (5.5 to 7.5 pH range). (54) A minimum pH of about 5.5 is desired in order to deter the adverse effects of aluminum and hydrogen ions and to increase basic cation adsorption. Sycamore grows in both acidic and alkaline soils; however, lime additions enhance growth on many of the acidic soils which are common in the southeastern, U.S.

Hardwoods, like all other living things, require nutrients in order to grow . The soil system must provide these nutrients in sufficient quantities if the trees are to grow well. By use of the dilute acid extractant, which is employed by most state soil testing labs in the southeast, very generalized critical soil nutrient levels have been established for southern hardwoods. These levels for the top 8" of soil are available phosphorous-20 pounds per acre, available potassium-100 pounds per acre, available calcium-400 pounds per acre, available magnesium-50 pounds per acre and available manganese-10 pounds per acre. If an extracted level falls below its critical level, then the soil is thought to be deficient in that nutrient. In addition, the nutrients need to be in good balance in the soil because very high values of one nutrient can inhibit the plant uptake of another nutrient.

Broadfoot describes several general soil characteristics that affect nutrient availability. First, he suggests that the more virgin (or less cultivated) the land, the less nutrient depletion that has occurred. Furthermore he found that the best sites tend to develop from alluvial material of mixed mineralogy which form more than 2% organic matter for their surface twelve inches. In addition, as the organic matter and the topsoil thickness decrease, the nutrient supplying potential was found to generally decrease.(54)

Even though nutrients may be available in large quantities, suggicient amounts of a nutrient or nutrients may not be taken up by the trees. This can be due to physical soil conditions (such as low moisture, low air, or compacted areas); or it could be caused by deficiencies in the tree's ability to "absorb" nutrients (physiological or genetic problems); or it could be caused by chemical imbalances. For example, high levels of hydrogen ions (low pH) inhibit the uptake of all other nutrients. Calcium is very effective in protecting the absorption mechanism from impairment by high hydrogen concentrations; however, the hydrogen still competes for "transport sites" into th e root.(44) Divalent cations, such as magnesium and calcium, can have their uptake impaired when low overall nutrient uptake occurs because these cations are absorbed slower by the root than are monovalent cations.(45) In addition, high levels of calcium can cause deficiencies in the uptake of sodium and other el ements with large hydrated radii by encouraging the absorption of potassium and other small-radii nutrients at an abnormally high rate, thus leaving fewer transport sites for sodium.(72)

The levels of nutrients in the foliage are somewhat related to the levels of nutrients absorbed by the plant roots. However, variable translocation and relocation rates over time, along with losses of nutrients from the plant, greatly complicate the use of foliar testing as an informative tool. However, Leaf recommends three criteria to use for determining sampling time. These criteria will help alleviate some of the intratree variability. The criteria are to sample at maximum differences between healthy and unhealthy trees, to sample at a stable nutrient level, and (of less priority) to sample in order to provide the maximum value of the nutrient element.(PL5) For his study with sugar maple, the most stable series of foliage nutrient levels was found to be about one month before autumn coloration. Other researchers have also presented valuable information on how to obtain meaningful foliage samples. Samples should only be obtained from codominant and dominant trees within the stand; furthermore, sampling should be restricted to the upper third of these trees' crowns-this is to insure that the samples came from vigorously growing areas.(PL6)

A few studies have been perfomed to examine critical foliar nutrient values for given ha rdwood species. In a hydroponic study with yellow poplar, a range of foliar percentage combinations of elements correlated with about the same amount of growth. Large ion antagonisms affected growth and thus they would not allow single element critical values to be developed.(8) Working with eastern cottonwood seedlings under a hydroponic system, seedlings showing the best growth have foliage concentrations of nitrogen at about 4%, while phosphorous concentrations were close to 0.6% and potassium concentrations were approximately 3.5%.(6) Less accurate field tests with Populus deltoides suggest rather low critical nutrient levels in the leaves of this species. They are as follows: nitrogen at 2.00%, phosphorous at 0.17%, potassium at 2.30% and magnesium at 0.18%.(50)

No rough critical values for nutrient levels in sycamore foliage have been developed. Since sycamore, like yellow poplar and the cottonwoods, requires highly fertile, non-acidic soils for optimum growth, it follows tha t the critical foliar nutrient levels will probably be high in comparison to those for pines and other less site-demanding species. A field study performed in Illinois found very poor correlations between foliar nutrient levels and sycamore growth; however, soil moisture and other factors complicated the results.(69) By use of established greenhouse procedures, involving hydroponic sys tems, critical nutrient levels for sycamore foliage can be developed. If intensive plantation culture continues for sycamore, developing reliable critical foliar nutrient levels or element interaction ranges will greatly aid in determining when and how to fertilize an existing stand.

Several studies have correlated environmental conditions to hardwood growth; however, much additional work needs to be done. Correlations which are found can not be accepted as evidence of cause and effect relations; nevertheless, they are helpful in interpreting and hypothesizing about basic physiological reasons for site productivity potentials. In addition, "soil site results apply only to the particular area studied and, further, only to the particular soil and topographic conditions sampled within the study area."(29) However, some solid hypotheses can be formed for similar environmental areas even if they are not sampled.

Most soil-site quality studies find soil depth, texture and drainage to be the most important soil features in prediction equations. In order to relate these and other environmental features to growth, a wide range of site quality must exist within the sample area.(29) Thus, the sampling scheme must contain sampling units which vary from poor to excellent growth of the test species. Within a given sample unit, however, growth should be very uniform.

Specific studies with hardwoods have related hardwood growth with environmental conditions. In a studyperformed in the Midsouth, two rough guides were constructed for predicting cottonwood growth on the basis of soil characteristics. The first guide involves the determination of soil texture, internal drainage and inherent moisture conditions. The second classification scheme involves characterization of the soil into soil series and phases and rates the soils on this basis.(17)

Environment-site quality studies have also been performed with many oak species. Cherrybark oak sites were evaluated in ~~a similar region as were cottonwood sites~~. Depth to mottling, topsoil depth, and depth to a hardpan were found to be the best soil predicting variables in assessing cherrybark oak growth potential. Increased depth for all of these three factors elevated the site index for this species.(52) Broadfoot also studied water oak sites for the same midsouth region. He prescribed three ways to predict water oak site quality on the basis of soil properties. They are as follows: the first and best method involves estimating exhangeable sodium, topsoil depth and the presence or absence of a hardpan; the second method involves the determination of soil texture, topsoil thickness, depth to gray mottles, inherent moisture conditions and the presence or absence of a pan; the third method requires classifying the soil into soil series and phases and then using average values for these categories.(91) Broadfoot also conducted a similar study on willow oak. Again he presented three methods for predicting site quality on the basis of soil properties. The most precise model involves the determination of the clay percentage in the three to four foot layer, the depth to gray mottles, the inherent moisture condition, and the presence or absence of a hardpan.(92) Beaufait studied the influences of soil and topography on the same species for the Mississippi river bottom and delta regions. He found that topography was an extremely important variable with small topographic changes causing relatively large site index changes. In order to partially control this variance, separate soil-site equations were prepared for each of four topographic classes (high ridge, low ridge, high flat and low flat). The most site-indicative soil factors were found to be the percent clay in the twelve to eighteen inch la yer and soil exchangeable potassium.(21)

The growth of sweetgum, another high quality hardwood species, has also been correlated to s oil properties. Three generalized guides for the mid-south are suggested. The first method involves determination of the clay percentage and excha ngeable potassium in the three to four foot soil layer. The second guide requires knowledge about the soil texture and drainage, while the third method is based on soil series and phases.

In general, soil series have been found to be poor predictors of forest site quality. More grow th variability has been found to exist within a soil series than between soil series for a given tree species.(999) In a study conducted in Virginia, little, if any, usable correlation existed between soil mapping units and the site index of yellow poplar.(10) Therefor e, foresters need to know more than just the soil series involved, in order to predict growth potential.

II. Method

A. Study Location

It is known that sycamore (Platanus occidentalis) will perform very well on many light to medium textured bottomland sites. However, there is limited acreage of this type and its value for other uses is often greater. Because of the large need of Champion Papers mill in Alabama for hardwood pulp, comvination operational a nd research plantations of different hardwood species were established on several predominantly upland sites in the early 1970's. My study was performed on one such plantation, which was planted to sycamore.

The main initial objective of the planting was to determine how sycamore would perform on a "non-hardwood" site. However, very large growth differences (with a range from ten foot to forty foot tall trees after six years) were observed throughout the 47-acre plantation. The site quality, as reflected by height grow th, rapidly and dramatically changed over the entire study area, even with small changes in elevation. Therefore, I was given the task of determining why these growth differences occurred. Now , some specifics about the stud y area.

The pla ntation is on a limestone-based predominantly upla nd site in the coasta l plain of northern Ala bama. The soils have a high silt content and generally range in texture from a silt loam to a clay loam throughout their profiles. The topography is semi-karst causing a very non-uniform land base. Slopes are generally less than 3%,but they are in constantly changing intensitie s and directions. This land, overall, is considered very productive for agriculture and had been in cotton before being purchased by Champion Papers as part of their mill site. It was decided by Gordon White of Champion Papers to use this abandoned farm land for a pilot sycamore planting.

In January 1971, Champion personnel received, graded and stored 1-0 sycamore see dlings from two state nurseries. The study area was plowed and disked for a cos t of ten dollars per acre. Following this, rows were marked off on the land at a cost of five dollars per acre. On the basis of recommendations from the N. C. State Forest Fertilization Cooperative, one ton per acre of agricultural lime was broa dcasted and twenty-five pounds per acre of 46% super phosphate was banded before planting. The costs for these soil additions, including application costs, totaled about $20.00 per acre. Between March 21 and April 5, 1971, seedlings with root collar diameters greater than ¼" were planted with a modified Stark cottonwood planter which subsoils to a 16" depth. The cost of the planting procedure including seedling costs, was about $17.00 per acre.

Cultivations were frequently performed on the plantation through the second growing season, the first being just two months after planting. Nitrogen was added at the start of the fourth growing season at a rate of 100 pounds of nitrogen per acre. No other treatments were applied to the plantation.

B. Design

Plots were selected throughout the plantation. Each plot is about five-hundredths of an acre in size containing about 27 trees at a 9' x 9' spacing. A group of trees was only selected as a plot if there was very good uniformity within the group and the growth performance was indicative of either excellent, good, fair or poor growth as we specified them. Ten excellent, ten good, ten fair and ten poor plots were established. All of the soil, topographic, and foliage data was collected on a plot basis.

For each of the forty test plots, soil samples from 0-3", 3-6", 6-10½, and 10½-15" were obtained from composits of twelve subsamples per depth per plot. Thus, a total of 160 samples (forty plots times four sampling depths) were available for analysis. All of the 160 samples were analyzed by the

N. C. Soil Testing Lab for exchangeable acidity, hydrogen, magnesium, ammonium, calcium, sodium, zinc, copper, manganese, and for available phosphorous, sulfate, nitrate and soluble salts. In addition, the percentage of organic matter and the pH were determined for these samples. The top two sample layers (0-3" and 3-6") were combined for all future tests with these samples, thus forming a 0-6" sample layer. I analyzed exchangeable aluminum for the 0-6", 6-10½", and 10½-15" samples for each plot (120 total samples) by the potassium chloride extraction technique. By use of this chemical data, the exchangeable hydrogen, percent base saturation and cation exchange capacity could be calculated.

The same 120 samples (three depths for forty plots) were also analyzed for two physical soil traits-particle size distribution and soil moisture-tension association. By use of the modified Day procedure, the approximate percentages of coarse sand, fine sand, coarse silt, fine silt and clay were determined. The exact method is taht used by the soil physics testing lab at N. C. State University. Soil moisture-soil moisture tension relationships were tested at the same lab. By use of initially saturated pressure plates, the percentage moisture withheld at one-tenth, one, five and fifteen atmospheres of tension was found for each of the 120 samples. From this, rough estimates can be made of total, potentially available water (.1 atm. moisture minus 15 atm. moisture) and total, potentially easily available moisture (.1atm. moisture minus 5 atm. moisture). In addition, by subtracting the moisture content at 15 atm. (wilting point approximation) from field soil moisture determinations, available field moisture can be approximated. Also, by subtracting the moisture content at 5 atm. of tension from field moisture determinations, very rough estimates of field easily available moisture can be calculated.

Other soil observations were also made in the study plot. A complete soil profile description down to 30 inches was done within each plot. The colors, general textures, irregularities, mottles and thicknesses of different layers were determined. A soil bucked auger and Munsell color book were used for this exercise.

Field soil moisture contents were determined for several soil layers for each plot at three different times. The three sampling times were early March (nearly saturated condition), middle May (extremely dry condition) and middle August (semi-dry condition). The soil layers sampled were 0-3", 3-6", 6-10½" and 10½-15" in early March and 0-6" and 6-10½" for the other two sampling periods. Duplicate samples were obtained when time permitted. Moisture determinations were made by the gravimetric procedure. After obtaining a sample, it was placed in a plastic bag which was then sealed. After the wet weight of the soil within a bag was determined, the sample was placed in an oven at 105°C for twenty-four hours. The weight was taken and percent moisture was calculated.

Bulk density determinations were also made for each plot. Four, three-inch bulk density cores were taken for both the 1½-4½" and the 7-10" layers within each plot. The 1½-4½" cores were used to represent the bulk density of the 0-6" soil layer while 7-10" cores represented the 6-10½" layer for the same determination. Samples were taken with a standard three-inch core sampler-specified for bulk density determinations. The samples were analyzed by the gravimetric procedure. The oven dry weight of the extracted soil cores was related to the fixed, known volume of the cores for bulk density calculations.

Soil strength, which is strongly related to incipient soil moisture, texture and bulk density conditions, was determined with a penetrometer.

The soil's resistance to penetration (soil strength) as measured in pounds per square inch was determined during early March (nearly saturated condition) and late August (semi-dry condition. The highest resistances within each of the 0-6", 6-12" and 12-18" layers were recorded for each repetition within each plot. In March, two readings per depth were taken in the planting row and a like number were taken between the rows for each of the forty plots. Because of the large intraplot variation involved with the March in-row values, all four of the readings per plot per depth were taken between the rows in August. The penetrometer which I used was only able to penetrate soil with resistance less than 950 pounds per square inch. Therefore, some penetrations did not go 18" into the soil during the semi-dry sampling period. When this was the case, I recorded the maximum depth of penetration and stated that the lower depths had a resistance of 1000 pounds per square inch.

Topography, as well as soils, was studied. An estimate of the micro-topography surrounding each plot was determined by use of an abney level. Slopes for distances of 100 feet from a plot center were measured in each of the eight cardinal directions. As the slopes changed along a hundred foot line, the length and position of each slope is recorded. A plot is about sixty feet by forty feet so the topography surrounding the plot is intensively studied. Since the topography is semi-karst, the micro-topographical effects are probably the most important.

In order to relate soil nutrient values and tree growth determinations to foliar nutrient levels, foliage samples were taken in mid-August. These samples were taken from trees within each plot; the samples came from sunlit branches in the upper third of the canopy of codominant or dominant trees. Selected, green, healthy leaves were taken from branches of three to six trees within each plot. The plot samples were analyzed separately. The three main leaf veins and petioles were discarded before the samples were ground and analyzed. The percent nitrogen, phosphorous, copper, calcium, magnesium, manganese and potassium in the forty plot samples were determined by standard procedures. The exact methods employed were those used at the forest soils research lab in the Research Triangle Park.

III. Results and discussions

A. Performance class means

SYCAMORE VOLUME PER ACRE DETERMINATIONS

Perf. Class	Tree Vol. cu.ft./acre outside bark	Tree Vol. cu.ft./acre inside bark	Theoretical Tree Vol. cu.ft./acre outside bark	Theoretical Tree Vol. cu.ft./acre inside bark
Excellent	1027.45[a]	824.75[a]	1215.5[a]	976.06[a]
Good	610.85[b]	435.15[b]	696.03[b]	495.20[b]
Fair	314.75[c]	158.96[c]	341.93[c]	172.54[c]
Poor	131.69[d]	6.805[d]	167.98[d]	8.59[d]

OTHER SYCAMORE GROWTH DETERMINATIONS

Perf. Class	Average tree height within plots	Average tree diam. within plots	Average height of nine largest plot trees	Average Volume of nine largest plot trees
Excellent	35.58[a]	4.76[a]	39.64[a]	3.367[a]
Good	28.27[b]	3.92[b]	30.97[b]	1.752[b]
Fair	22.25[c]	2.70[c]	24.71[c]	0.843[c]
Poor	13.84[d]	1.48[d]	16.50[d]	0.393[d]

Note: Significances that are shown are between performance classes for a given growth determination. Table values are the means for respective growth determinations and performance classes. Theoretical tree volumes are obtained by inserting the average individual tree volume (plot basis) for any missing trees within the plot.

Volume per tree (o.b.)= $.21099 + .00221(dbh)^2h$ *

Volume per tree (i.b.)= $.00204(dbh)^2h - .06477$

One necessity in this study was to select plot classes which possessed distinctly different levels of tree growth. This objective was obtained. In this study, a given performance class was significantly different from all of its counterparts in all tree growth analyses. These growth analyses includedmeasurements of tree heights, volumes and diameters. The figures in the table represented growth after one year in the nursery bed and seven years in the plantation.

The actual tree volume per acre (o.b.) and the average height of the nine largest plot trees are the most important growth factors in assessing site index. This is due to the fact that the height of the average dominant tree is the most standard measure of site potential, and because tree volume (o.b.) is what the producer will ultimately be able to utilize in a mill.

PARTICLE SIZE ANALYSES

Perf. Class	Layer	Coarse Sand 2-.11mm	Fine Sand .11-.06	Coarse Silt .06-.004	Fine Silt .004-.0025	Clay .0025-
	0-6"					
Exc.		23.19[a]	5.88[a]	45.38[a]	4.81[a]	20.75[b]
Good		38.70[b]	6.41[a]	36.61[b]	3.80[b]	14.48[a]
Fair		38.24[b]	6.48[a]	32.61[b]	3.41[b]	19.26[b]
Poor		34.56[b]	6.62[a]	34.44[b]	3.12[b]	21.25[b]
	6-10½"					
Exc.		19.50[a]	5.88[a]	47.38[a]	4.50[a]	22.75[ab]
Good		34.58[b]	6.35[a]	48.62[b]	4.38[a]	18.23[b]
Fair		29.39[b]	6.36[a]	34.52[b]	3.52[a]	25.68[a]
Poor		27.00[ab]	5.75[a]	35.62[b]	3.38[a]	28.25[a]
	10½-15"					
Exc		18.50[a]	5.88[a]	48.62[a]	4.38[a]	22.62[bc]
Good		30.00[b]	6.04[a]	38.65[b]	3.02[a]	22.29[c]
Fair		28.75[b]	5.68[a]	34.32[b]	3.07[a]	28.18[ab]
Poor		25.50[ab]	5.75[a]	35.50[b]	2.50[a]	30.75[a]

Note: Significances that are shown are between performance classes at a given depth. Table values are the means for respective particle sizes and soil layers.

FOREST RESOURCES
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Down to fifteen inches, excellent plots averaged significantly less coarse sand than did the plots of other performance classes. In addition, there was a small, insignificantly downward trend in percent coarse sand as one moved from good to fair and then to poor plots. In conjunction with this was an upward trend in percent clay moving from good to fair and finally to poor plots. The average clay level in the good plots was significantly less than in the fair and poor plots. Unlike sand and clay percentages, percent silt was nearly the same for the good, fair and poor plots. However, percent coarse silt was significantly greater, on the average, in the excellent plots than in plots of other performance categories. Particle class distributions were substantially different between performance class means.

SOIL MOISTURE-TENSION ASSOCIATIONS

Perf. Class	Layer	Soil % Moist @ 0.1 atm.	Soil % Moist. @ 1.0 atm.	Soil % Moist.@ 5.0 atm.	Soil % Moist.@ 15.0 atm.	Pot.Avail. Water .1-15atm.	Pot.Easy Avail.Water .1-5atm.
	0-6"						
Exc.		30.10[a]	18.89[a]	12.07[a]	10.95[a]	19.15	18.03
Good		25.06[b]	13.20[b]	8.24[b]	7.48[b]	17.58	16.83
Fair		25.15[b]	14.30[b]	9.68[b]	9.06[ab]	16.09	15.47
Poor		27.12[b]	15.27[b]	10.56[ab]	9.35[ab]	17.77	16.56
	6-10½"						
Exc.		29.92[a]	19.22[a]	12.43[b]	11.23[ab]	18.70	17.50
Good		26.26[b]	14.94[b]	9.87[a]	8.96[b]	17.31	16.39
Fair		27.33[ab]	17.02[ab]	11.84[b]	10.93[ab]	16.40	15.49
Poor		29.25[ab]	18.04[ab]	13.15[b]	11.82[a]	17.43	16.10
	10½-15"						
Exc.		30.17[a]	19.14[a]	12.39[ab]	11.02[ab]	19.15	17.78
Good		27.80[a]	16.13[a]	11.05[a]	9.90[b]	17.90	16.75
Fair		28.91[a]	17.80[a]	12.59[ab]	11.88[ab]	17.03	16.32
Poor		28.61[a]	17.99[a]	13.61[b]	12.50[a]	16.12	15.00

Note: Significances that are shown are between performance classes in a given layer for a soil moisture-tension category. Table values are the means for respective soil moisture-tension categories, soil layers, and performance classes.

On the average, soils of excellent plots held more water at all soil tensions tested (0.1, 1, 5, and 15 atmospheres) than did their counterparts. In addition, potentially available water and potentially easily available water were usually greater in the excellent plots(a result of more silt-size particles, good soil structure, and good organic matter relations). In contrast, good plots averaged less water than did the other plots at all tested soil tensions. This was at least partially due to lower clay levels in the good plots(on the average). As expected, slight, but continuous, downward trends in potential water availabilities existed for the 10½-15" soil layers as one went from excellent to good to fair and finally to poor plot means. This was probably due to better soil structure and improved organic matter relations in the plots producing superior growth.

SOME CHEMICAL SOIL VALUES CONCERNING ACIDITY

Perf. Class	Layer	Rough Acidity meq/100g	NH_4^+ meq/100g	pH	Mn^{+2} meq/100g
	0-3"				
Exc.		1.734^{c}	$.1921^{a}$	5.51^{a}	$.446^{a}$
Good		1.177^{a}	$.1646^{a}$	5.65^{a}	$.341^{b}$
Fair		1.225^{a}	$.1492^{a}$	5.55^{a}	$.271^{b}$
Poor		1.219^{a}	$.1529^{a}$	5.53^{a}	$.306^{b}$
	3-6"				
Exc.		1.972^{a}	$.1730^{a}$	5.32^{a}	$.414^{a}$
Good		1.284^{b}	$.1467^{ab}$	5.54^{a}	$.304^{b}$
Fair		1.312^{b}	$.1254^{b}$	5.38^{a}	$.233^{b}$
Poor		1.367^{b}	$.1254^{b}$	5.34^{a}	$.221^{b}$
	6-10½"				
Exc.		1.938^{a}	$.1712^{a}$	5.300^{a}	$.4424^{a}$
Good		1.397^{b}	$.1372^{b}$	5.408^{a}	$.3157^{b}$
Fair		1.496^{b}	$.1095^{b}$	5.218^{a}	$.2008^{c}$
Poor		1.536^{b}	$.1029^{b}$	5.240^{a}	$.1929^{c}$
	10½-15"				
Exc.		1.824^{a}	$.1672^{a}$	5.300^{a}	$.4398^{a}$
Good		1.538^{a}	$.1300^{b}$	5.350^{a}	$.3358^{b}$
Fair		1.639^{a}	$.0958^{c}$	5.127^{a}	$.1706^{c}$
Poor		1.635^{a}	$.0955^{bc}$	5.170^{a}	$.1704^{c}$

Note: Significances that are shown are between performance classes in a given layer for a chemical soil category. Table values are the means for respective soil chemical categories, soil layers and performance classes.

Down to fifteen inches, excellent plots averaged more soil ammonium (extracted from nearly saturated field conditions), manganese and total acidity than did their counterparts. In addition, good plots averaged higher levels of exchangeable ammonium and manganese than did poor or fair plots. The solid positive trend of exchangeable manganese with growth was one surprise of this study, especially since all the soil manganese levels shown in the table are at least ten times greater than the suggested critical value for hardwoods. Since more than half of the better plots (plots in the excellent and good performance classes) were probably derived from teraace alluvium, it may have been that the old alluvium had inherently more manganese than the upland, residual parent material-from which all of the fair and poor plots were derived. In addition, the higher organic matter concentrations in the better plots may have increased the exchange sites for manganese ions. Soil chemical properties relating to acidity showed some interesting relati onships with growth performances.

NONACIDIC SOIL CHEMICAL LEVELS

Perf. Class	Layer	P ppm	K meq/100g	Ca meq/100g	Mg meq/100g	O.M. %
	0-3"					
Exc.		17.35^{c}	$.350^{a}$	3.519^{a}	$.559^{a}$	1.53^{a}
Good		10.83^{b}	$.216^{b}$	2.935^{a}	$.424^{b}$	1.23^{b}
Fair		7.17^{a}	$.226^{b}$	2.907^{a}	$.451^{b}$	1.23^{b}
Poor		6.06^{a}	$.216^{b}$	2.816^{a}	$.483^{ab}$	1.12^{b}
	3-6"					
Exc.		11.94^{c}	$.304^{a}$	2.914^{a}	$.487^{ab}$	1.32^{a}
Good		7.00^{b}	$.168^{b}$	2.786^{a}	$.383^{b}$	$.925^{b}$
Fair		4.54^{a}	$.164^{b}$	2.806^{a}	$.458^{ab}$	$.836^{b}$
Poor		3.58^{a}	$.164^{b}$	2.861^{a}	$.522^{a}$	$.730^{b}$
	6-10½"					
Exc.		8.232^{a}	$.2699^{a}$	2.809^{a}	$.4922^{b}$	1.220^{a}
Good		4.061^{b}	$.1458^{b}$	2.590^{a}	$.4308^{b}$	$.708^{b}$
Fair		2.293^{c}	$.1377^{b}$	2.663^{a}	$.5706^{b}$	$.464^{b}$
Poor		1.784^{c}	$.1446^{b}$	2.843^{a}	$.7096^{a}$	$.340^{b}$
	10½-15"					
Exc.		5.925^{a}	$.2515^{a}$	2.822^{a}	$.5205^{b}$	1.130^{a}
Good		3.090^{ab}	$.1386^{b}$	2.641^{a}	$.5108^{b}$	$.633^{c}$
Fair		2.002^{ab}	$.1262^{b}$	2.476^{a}	$.6678^{ab}$	$.354^{bc}$
Poor		1.800^{b}	$.1299^{b}$	2.592^{a}	$.7931^{a}$	$.250^{b}$

Note: Significances that are shown are between performance classes in a given layer for a chemical soil category. Table values are the means for respective soil chemical categories, soil layers and performance classes.

Mean performance class values of soil phosphorous were quite different. As the performance class' status increased (status which was based on tree growth), the mean level of phosphorous in the soil also increased. Much of this relationship was statistically significant. Soil phosphorous (0-6" layer) was also very important in regression equations, as a factor positively relating to tree growth.

Throughout the top fifteen inches of soil, the potassium level was significantly greater, on the average, in excellent plots than in other plots. The soil potassium levels were fairly much the same for the good, fair and poor plots.

Both soil calcium and soil magnesium values were relatively high for all performance classes. Since the soils were developed from limestone-based material (either residual or alluvial), high levels of calcium and probably magnesium would be expected. However, the negative associations of magnesium levels in the 6-15" soil layers with performance class statuses were not expected for sycamore. In addition, it was hypothesized that some positive relationships would exist between soil calcium levels and performance class statuses; however, these associations were not found in this study. Probably, the main reasons for these surprising results were the high levels of these two nutrients in the soils of all plots.

Percentage of organic matter in the soil was highly, positively related to performance class status. Down to fifteen inches, the excellent plots averaged significantly more organic matter in their soils than did the other plots. Only one other significant difference existed; however, the mean organic matter values for performance classes progressively increased as their statuses increased.

Recall that many of the soils of the better plots were probably derived from old terrace alluvium, which had a different element constituency than the residual, upland parent material from which the soils of the fair, poor and some of the better-performing plots were derived. This alluvium may have contained higher levels of manganese and lower levels of magnesium than its upland counterpart. Another theory may explain the differential levels of soil magnesium and manganese. Organic matter may have been a more efficient exchange site for manganese than for magnesium; conversely, clay may have been more efficient in providing exchange sites for magnesium than for manganese. If this were true, it would explain the higher soil magnesium levels in the poorer plots (especially in the 6-10½" and 10½-15" soil layers where the clay percentage of poorer plots was considerably higher than that of better plots). It would also explain why the soil manganese level was positively correlated with the soil organic matter percentage.

SOIL EXCHANGEABLE ALUMINUM

Perf. Class	0-6" Layer Exch. Alum. meq/100g	6-10½" Layer Exch. Alum. meq/100g	10½-15" Layer Exch. Alum. meq/100g
Excellent	.230[a]	.2893[a]	.2553[a]
Good	.0993[a]	.2061[a]	.2652[a]
Fair	.134[a]	.3413[a]	.4533[a]
Poor	.254[a]	.3527[a]	.4312[a]

GENERAL SOIL CHEMICAL VALUES

Perf. Class	CEC 0-3"	%B.S. 0-3"	CEC 3-6"	%B.S. 3-6"	CEC 6-10½"	%B.S. 6-10½"	CEC 10½-15"	%B.S. 10½-15"
Exc.	6.86[a]	74.72[a]	6.34[a]	69.04[a]	6.211[a]	68.88[a]	6.074[a]	69.80[a]
Good	5.29[b]	76.59[a]	5.11[a]	73.69[a]	5.027[a]	71.28[a]	5.283[a]	70.10[a]
Fair	5.30[b]	76.55[a]	5.16[a]	74.21[a]	5.226[a]	71.32[a]	5.230[a]	68.59[a]
Poor	5.19[b]	75.59[a]	5.27[a]	73.86[a]	5.526[a]	71.92[a]	5.421[a]	69.94[a]

Note: Significances that are shown are between performance classes in a given layer for a chemical soil category. Table values are the moans for respective soil chemical categories, soil layers and performance classes.

Cation exchange capacity values are in meq/100g.

For all sample layers, there were no significant differences in the mean exchangeable, aluminum levels of the four plot classes. There did seem to be some evidence of higher aluminum levels in the fair and poor plots for the lower two sampling units. This may have been caused by higher clay concentrations.

Estimates of soil cation exchange capacity and percent base saturation were about the same for all performance classes. The only exception to this seems to have been with the excellent plots which had consistently higher levels of total exchangeable cations than did the other plots. However, this difference was only significant in the 0-3" soil layer.

Note that the cation exchange capacities for all plot classes were relatively low (about 6 meq/100g.) in all sample layers. However, the estimates of the percent base saturations were very high for all performance classes (values around 70%). Recall that the values obtained for soil exchangeable acidities in this study were rough estimates; therefore, percent base saturation and cation exchange capacity values could be in considerable error.

SOIL MOISTURE IN THE FIELD AT DIFFERENT TIMES

TOTAL SOIL MOISTURE IN THE FIELD AT DIFFERENT TIMES

Perf. Class	March 0-6" %wt.	March 6-10½" %wt.	March 10½-15" %wt.	May 0-6" %wt.	May 6-10½" %wt.	August 0-6" %wt.	August 6-10½" %wt.
Exc.	21.170[a]	20.332[a]	20.538[a]	16.649[a]	18.181[a]	15.864[a]	14.661[a]
Good	17.201[b]	17.487[a]	18.363[a]	10.614[b]	14.550[b]	12.914[a]	13.209[a]
Fair	15.468[b]	16.818[a]	17.702[a]	10.676[b]	15.118[b]	13.940[a]	15.123[a]
Poor	------	------	------	10.429[b]	15.395[b]	14.805[a]	16.723[a]

AVAILABLE SOIL MOISTURE IN THE FIELD AT DIFFERENT TIMES (ESTIMATE)

Perf. Class	March 0-6" %wt	March 6-10½" %wt	March 10½-15" %wt	May 0-6" %wt	May 6-10½" %wt	August 0-6" %wt	August 6-10½" %wt
Exc.	10.219	9.106	9.523	5.698	6.955	4.913	3.435
Good	9.716	8.532	8.464	3.129	5.595	5.429	4.254
Fair	6.410	5.885	5.822	1.618	4.185	4.882	4.190
Poor	-----	-----	-----	1.076	3.577	5.452	4.905

EASILY AVAILABLE SOIL MOISTURE IN THE FIELD AT DIFFERENT TIMES (ESTIMATE)

Perf. Class	March 0-6" %wt	March 6-10½" %wt	March 10½-15" %wt	May 0-6" %wt	May 6-10½" %wt	August 0-6" %wt	August 6-10½" %wt
Exc,	9.100	7.906	8.148	4.579	5.755	3.794	2.235
Good	8.964	7.616	7.316	2.377	4.679	4.677	3.338
Fair	5.791	4.979	5.115	0.999	3.279	4.263	3.284
Poor	-----	-----	-----	-0.133	2.241	4.243	3.569

Note: Significanees that are shown are between performance classes for a given field moisture category. Table values are the means for respective moisture categories and performance classes.
Soil is nearly saturated in March; dry in May and semi-dry in August.

Sampling for March soil moisture was interrupted by rainfall. Only eighteen plots (five excellent, five good and eight fair plots) were sampled before rain made any future samples illegitimate. On the basis of this restricted sample, nearly saturated field moisture (March reading) may have been positively related to class status, especially in the top six inches of soil. In addition, the portion of this moisture that was available and easily available also followed the same positive association with class status.

The study area had not received any rain for a few weeks before the May moisture sampling date. The soil appeared to be dry and moisture availability was limited on some plots. The excellent plots averaged significantly higher levels of field moistures (0-6" and 6-10½" soil layers) than did the other plots. Good, fair and poor plots apparently held basically the same total "dry" (May) moisture. However, May available and easily available moisture levels were more specific for good, fair and poor plots, resulting in positive associations of these two factors with class statuses for both soil layers.

In mid-August, field moisture samples were also taken. There was a light rain a couple of days before sampling but no rain occurred the two days while sampling was bei ng conducted. No trends existed between total August field moisture and class status. However, a slightly negative association existed in the 6-10½" soil layer between class status and available water level(this was true for both easily available and total available water). This was probably principally due to more roots and thus, more water uptake capability in the 6-10½" soil layer of the better producing plots. The light rain that occurred a couple of days before sampling may have replinished some water deficiencies in the 0-6" layer.

FOLIAR NUTRIENT LEVELS

Perf. Class	Mn %	Cu ppm	P %	N %	K %	Ca %	Mg %
Exc.	.0168[a]	4.124[a]	.1412[a]	2.325[a]	.660[a]	1.428[c]	.213[a]
Good	.0167[a]	5.680[b]	.1357[ab]	2.051[b]	.744[a]	1.082[a]	.246[a]
Fair	.0126[b]	4.428[ab]	.1317[ab]	1.789[c]	.750[a]	.896[ab]	.227[a]
Poor	.0104[c]	4.638[ab]	.1248[b]	1.642[c]	.687[a]	.745[b]	.217[a]

Note: Significances that are shown are between performance classes for a given foliar nutrient category. Table values are on a weight basis and they are the means for respective foliar nutrient categories and performance classes.

In this study, the foliar levels of nitrogen, phosphorous, manganese and calcium positively related to the growth potential of sycamore. It should be noted, that for the study location, foliar phosphorous levels were less indicative of site index than were soil phosphorous (wet soil) values.

Percent nitrogen in the foliage was positively related to class status. All of the class means were significantly different except for the means of the fair and poor plots. Note that the mean nitrogen levels for the excellent and good plots were 2.325 and 2.051, respectively. These results suggest a lower critical nitrogen level than some have thought.

Likewise, foliar calcium levels seem to have been strongly, positively related to performance class status. The mean values of both the excellent and good plots were above 1% calcium (by weight) in the foliage. Adequate soil calcium probably existed in all performance classes (all performance classes average more than 1,000 ppm of calcium in the top 8" of soil). This suggests that the limiting factor was a constituent part of the uptake process and not of calcium availability. The 1% level for calcium and the 2% level for nitrogen are two of the best field estimates of critical nutrient levels that can be proposed by this study.

Manganese levels in the foliage also related to sycamore growth in this study. Recall that, surprisingly, soil manganese levels were highly, positively related to growth. Therefore, more manganese was available for uptake in the better plots, even though the average soil manganese level of the poor plots was more than ten times greater than the rough, critical level for hardwoods. As was the case with another divalent nutrient (calcium), the differential foliage concentration of manganese seems to have been partially the result of the uptake mechanism. Divalent cations are normally taken up slower than monovalent cations; however, during periods of moisture stress, the differential uptake of these two types of cations could be dramatic. Therefore, the higher foliar levels of manganese and calcium in the better plots may have been somewhat indicative of superior moisture relations. Because of foliar calcium's higher correlation with May field moisture, calcium foliar levels were probably more dependent on moisture relations than were manganese foliar concentrations. It may be that under a good moisture regime and with sufficient soil nutrients, calcium foliar levels will exceed 1% and manganese foliar levels will exceed .015% in sycamore trees in the appropriate sampling period.

Foliar potassium, copper and magnesium showed few relationships to sycamore growth. Copper values were very small (only four to six ppm.) and related poorly to growth. Potassium is a monovalent cation with a small hydrated radius. Thus, since soil calcium was high (protecting the root uptake mechanism and encouraging uptake of small radii ions), potassium was taken up in relatively high amounts even by poor plots. This also suggested that potassium uptake was not influenced as much by moisture relations as was plant uptake of calcium. Foliar magnesium levels were about the same for all performance classes. This may have been due to the hypothesis that the better moisture relations of the high performance plots was offset by the higher levels of soil magnesium (especially in the 6-10½" and 10½-15" layers) in the poorer performing plots. In addition, the high level of soil calcium may have been moderating the uptake of magnesium by the sycamore species.

SOIL STRENGTH

Perf. Class	March 0-6" lbs/in^2	March 6-12" lbs/in^2	March 12-18" lbs/in^2	August 0-6" lbs/in^2	August 6-12" lbs/in^2	August 12-18" lbs/in^2
Exc.	177.500[a]	313.750[a]	360.313[a]	880.000[ac]	929.375[a]	932.750[a]
Good	245.250[a]	302.750[a]	254.500[a]	875.625[a]	836.625[a]	861.500[ab]
Fair	201.250[a]	207.187[a]	269.375[a]	717.500[b]	640.750[b]	756.375[b]
Poor	183.333[a]	260.416[a]	352.500[a]	735.375[bc]	653.500[b]	718.000[b]

Note: Significances that are shown are between performance classes for a given soil strength category. Table values are the means for respective soil strength categories and performance classes.
Soil is nearly saturated in March, while it is semi-dry in August.

For soil strength determinations under nearly saturated, March conditions, no significant differences existed between the means of the different performance classes. The soil of the average plot had a resistance of about 200 pounds per square inch in the top six inches; this resistance to penetration increased to about 300 pounds per square inch in the twelve to eighteen inch soil layer. As the soil resistance goes above 300 pounds per square inch, it is thought that the roots of some agronomic crops are adversely affected (pers. comm.-Dr. K. Cassel). However, this data suggests that sycamore roots successfully penetrated through soil material that was "stronger" than 300 pounds per square inch. Remember that the maximum soil resistance in a given layer for a given repetition was recorded as the respective soil resistance value.

Soil strength determinations were again taken under semi-dry moisture conditions in August. Recall that the instrument rod could not penetrate material that was stronger than 1,000 pounds per square inch. Therefore, if the rod encountered stronger material, the layer and all subsequent lower sample layers were given a value of 1,000 pounds per square inch for that repetition. Therefore, August resistance values are fairly inaccurate. Despite this inaccuracy, there seems to have been some trend of higher soil strength in the better plots for the lower soil layers, in contrast to the same lower layers in poorer producing plots. This may have been partly due to more available water, for this sampling date, in the 6-10½" soil layer of poorer plots, in contrast to the same soil layer of superior growing plots.

Since the organic matter content and particle size analysis of the better performing plots were generally superior to that of the less productive plots, these higher site index plots probably possessed better soil structure, which allowed for good root penetrability despite the higher soil strength.. In addition, there was less clay in the 6-15" soil layer of the better plots, as compared to the same soil layer of poorer growing plots. In general, roots can better penetrate high strength soil material if the clay percentage is low. Therefore, tree roots in superior growing plots held this advantage. Soil strength showed some small, but interesting, relationships to sycamore tree growth.

BULK DENSITY

Perf. Class	0-6" g/cm^3	6-10½" g/cm^3
Excellent	1.430[a]	1.514[a]
Good	1.526[b]	1.538[a]
Fair	1.545[b]	1.514[a]
Poor	1.547[b]	1.545[a]

Note: Significances that are shown are between performance classes for a given bulk density category. Table values are the means for respective bulk density categories and performance classes.

Soil bulk density determinations were also taken in August, 1977. The only noticeable difference was the significantly lower mean bulk density of the 0-6" soil layer in the excellent plots. This was mainly due to higher organic matter concentrations, more root mass and improved soil structure in these rapidly growing plots. This low bulk density allowed for good water infiltration, water percolation and root penetrability.

AVERAGE SLOPES INTO THE PLOT CENTERS FROM 100 FT. AWAY

Perf. Class	Net Slope(ft)/100ft.	Absolute Value of Individual Slopes (ft)/100ft.
Excellent	-0.642[a]	0.909[b]
Good	-0.521[a]	1.606[c]
Fair	-0.293[a]	2.453[a]
Poor	1.117[b]	2.091[ac]

Note: Significances that are shown are between performance classes for a given microtopographical category.
Table values are the means for respective microtopographical categories and performance classes.
Slopes are taken from each of the eight cardinal directions for every plot.

Microtopography is normally a very important environmental factor in predicting the site index of hardwoods. The topography of the study location is semi-karst causing slopes on the land to change in intensity and direction within very short distances. Each study plot was roughly about the same size (approximately seventy feet by forty feet); thus, only a portion of an excellent area was sampled by an excellent plot. This also held true for the other performance classes. Therefore, the micro-topography surrounding a given plot was not only related to the growth performance of the plot,but it was also a function of the percentages of the surrounding area in the different performance classes. Despite this problem, clear trends were found as a result of taking slopes into the plot centers. These slopes were taken from 100 feet away for each of the eight cardinal directions from plot center. As the slopes changed along each 100 foot route, the distance of the slope and the slope reading were taken. Notice that there was a net downward slope (from 100 feet away) into the plot centers of mean excellent, good and fair plots. This suggests that these areas received a net accumulation of water, runoff, and nutrients from the land around them. As predicted, the poorer plots, on the average, had a net positive slope going from the surrounding land into their plot centers, this meant that the poorer plots were generally at higher elevations than the land immediately surrounding them, and hence these "knolls" released net quantities of water, runoff and nutrients to the adjacent land. As one went from poor to fair to good and finally to excellent plots, one reached plots which were in progressively lower, relative, landscape positions.

In order to determine just the "flatness" surrounding plot centers, all slopes,both positive and negative, were treated as positive (absolute value determination). The plot centers of better plots had flatter land immediately surrounding them than did the plot centers of poorer producing sample units. The fair plots averaged the highest "hilliness value" because they usually occupied the upper and middle side slope positions. The good plots occupied the lower, generally slightly concave, side slope positions or the upper part of depress ional areas. The excellent plots were almost strictly in depressional areas, while the poor plots were on knolls or high flats.

SOIL PROFILES - DEPTH TO A RED COLOR

Perf. Class	Depth to red color	Number of plots where red color is not present by 30 inches	Number of plots where red color is present by 30 inches
Exc.	28.70[c]	9	1
Good	15.81[b]	3	7
Fair	3.570[a]	0	10
Poor	3.940[a]	0	10

Note: Profiles were taken down to 30 inches. If a red color was nor present by 30 inches, then 30 inches was inserted as the depth to a red color for that plot profile. Significances that are shown are between performance classes for differing mean depths to a red color.

According to the Lawrence County soil survey conducted by the Soil Conservation Service, most of the soils near the study area were derived from limestone residuum or alluvial deposits which came from limestone-based material. Many of these soils developed brown or red colors in their B horizons. Many, but not all of the upland soils developed red colors in part of their B horizons. Therefore, the depth to a red soil color was developed as a variable in growth predictions. Soil profiles were only taken to thirty inches. If a red color did not exist before thirty inches deep into the soil, then thirty inches was inserted as the depth to a red color. In addition, both the excellent and good plots had mean performance averages for depth to a red color that were deeper than those for fair and poor plots. Notice that nine out of the ten excellent plots and three out of the ten good plots did not reach a red color by thirty inches. This fact, along with the uniformity within each of these twelve profiles (nine excellent and three good) suggests that these plots may have developed in old terrace positions. Most of the rest of the plots appeared to be on upland positions. In most plots, the only difference between lower topsoil and upper subsoil layers were very slight changes in texture and structure. Usually, I could not accurately determine where these changes occurred, therefore, I did not use topsoil depth as a variable for predicting growth.

POUNDS PER ACRE OF AVAILABLE NUTRIENTS IN THE SOIL

SOIL NUTRIENTS

rf. lass		K	Ca	Mg	Mn	NH_4	Al	P
c.	lbs/a 6"slice	255.414	1289.13	117.24	236.34	65.87	124.01	29.29
c.	lbs/a 8"slice	325.761	1664.47	157.71	317.33	86.46	176.02	34.78
od	lbs/a 6"slice	150.031	1146.47	98.141	177.24	56.14	53.58	17.84
od	lbs/a 8"slice	188.043	1492.44	133.07	235.04	74.65	90.63	20.54
ir	lbs/a 6"slice	152.474	1144.97	110.57	138.51	49.54	72.46	11.71
ir	lbs/a 8"slice	188.373	1500.80	156.83	175.27	62.71	133.82	13.24
or	lbs/a 6"slice	148.799	1138.23	122.15	144.74	50.20	136.77	9.64
or	lbs/a 8"slice	182.656	1518.06	179.67	180.06	62.57	200.18	10.83
ugh rdwood itical lue	lbs/a 8"slice	100	400	50	10	------	-------	20

te: Rough, critical hardwood levels are on the basis of the dilute acid extractant used in the majority of soil testing laboratories in the South.

Since nearly all pounds per acre estimates for mineral soils are based on two million pounds of soil per acre - six-inch slice, this value was used in my calculations. I also estimated that , for an eight-inch slice, two and two-thirds million pounds of soil were present in an acre. More accurate pounds per acre, and thus parts per million, estimates could have been formulated by using respective bulk densities in the calculations ; however, the resulting values could not be easily compared to nutrient concentrations in studies where bulk densities are not taken. Since almost no bulk density samples are taken in conjunction with soil nutrient sampling in forestry, it appeared to be most useful to employ the less accurate two million and two and two-thirds million pound estimates for evaluation purposes.

Note that all the pounds per acre values representing mean nutrient values of respective performance classes were generally greater than their nutrient's rough, critical value for hardwoods. The only exception to this was with phosphorous, where the pounds per acre (8-inch slice) of this nutrient were dramatically less than its respective critical level.

Recall that, in my study, all of the soil nutrient samples for phosphorous and ammonium were taken under moist, nearly saturated field conditions. The amount of moisture in the soil did seem to affect the phosphorous and ammonium concentrations, within a given sample unit; however, it did not seem to have had much effect on the potassium, calcium, magnesium, manganese or aluminum concentrations. It appeared that under a dry soil condition, the soil levels of both phosphorous and ammonium were less than their respective levels under a nearly saturated field condition. However, too few dry soil samples were taken, so this could not be proved for this location.

Note the substantially higher average pounds per acre in the excellent plots for potassium, manganese and phosphorous over the average levels of the respective nutrients in poorer performing plots. Also, the pounds per acre of phosphorous and manganese had a solid positive relationship with performance class status. Pounds per acre results showed important trends.

Variability in Sample Sizes

The initial study design was ten plots for each of the four performance classes. However, weather conditions, time restrictions or plot destruction caused the total number of test plots to be more or less than forty for some determinations. In early March, forty plots (ten in each performance class were delineated). I was only able to obtain samples, that would be used for determining chemical soil properties, particle size analyses and soil moisture-tension associations, from thirty five of the forty plots. In addition, I was only able to collect field, soil moisture samples from nineteen of the forty plots before rain came- making all future moisture samples for that period illegitimate. Penetrometer readings were taken on all forty of the plots.

When I returned to the site in mid-May, five plots (four good plots and one fair plot) had been destroyed when they expanded the waste area for the paper mill. Three (two good and one fair) of the five destroyed plots had been sampled back in March for chemical soil properties, particle size analyses and soil moisture-tension associations. I delineated five new plots (four good and one fair) to substitute for those destroyed, however, any soil information which I had collected on the destroyed plots back in March was also used in computing performance group means and standard deviations. The three plots remaining intact that had not been sampled for chemical soil properties, particle size analyses and soil moisture-tension associations in March were sampled in May for these factors. In addition, the new five plots were sampled for these same determinations. Unfortunately, the levels of soil anions (phosphorous, nitrate and sulfate), along with soil ammonium, was appreciably different in the dry, May soil than in the wet, March soil. Therefore, values for these chemical factors based on the samples taken from eight plots in May could not be used.

Several field determinations were replicated within a plot at a given depth. In May, duplicate field moisture samples were taken for the 0-6" and 6-10½" soil layers in each plot. In August, duplicate field moisture samples were taken for the 0-6" layer in each plot. In March and August, replications were taken for soil strength determinations in each soil layer of each plot. Average respective values for a plot-depth were used in regressions, comparisons and correlations.

Bulk density findings were also replicated. Four bulk density determinations were made for each plot-depth. A nested statistical design was employed in analyzing this data. Nested designswere not used for other replicated factors for one of two reasons. Either there were just two replications per plot-depth yielding very unreliable estimates of intra plot variability at a given depth, or in the case with August penetrometer readings, the instrument could not record some very high readings that were present in the field.

III. B. Correlations

HIGH CORRELATIONS OF CHEMICAL SOIL PROPERTIES WITH TREE MEASUREMENTS

TREE MEASUREMENT - TREE VOLUME (o.b.) PER ACRE

Chem. Soil Prop.	Correlation Coefficients (r) 0-3" Soil Layer	3-6" Soil Layer	6-10½" Soil Layer	10½-15" Soil Layer	Probability that rho=0 0-3" Soil Layer	3-6" Soil Layer	6-10½" Soil Layer	10½-15" Soil Layer
P	.84061	.83756	.86524	.80906	.0001	.0001	.0001	.0001
K	.58041	.65008	.65956	.63759	.0001	.0001	.0001	.0001
Mg	.30625	-.07807	-.42843	-.49788	.0546	.6321	.0058	.0011
Mn	.54310	.68766	.75949	.78355	.0013	.0001	.0001	.0001
NH_4	.52723	.60268	.70827	.74845	.0019	.0003	.0001	.0001
O.M.	.532~~3~~12	.62397	.73344	.76729	.0004	.0001	.0001	.0001

TREE MEASUREMENT - AVERAGE HT. OF NINE TALLEST PLOT TREES

P	.80434	.82232	.82099	.76826	.0001	.0001	.0001	.0001
K	.59283	.65726	.66669	.65632	.0001	.0001	.0001	.0001
Mg	.26595	-.13654	-.51309	-.57725	.0972	.4008	.0007	.0001
Mn	.52060	.67602	.73757	.75165	.0023	.0001	.0001	.0001
NH_4	.49975	.57651	.69366	.70284	.0036	.0006	.0001	.0001
O.M.	.57931	.66651	.76294	.78666	.0001	.0001	.0001	.0001

TREE MEASUREMENT - AVERAGE d.b.h. (o.b.)

P	.77015	.79122	.78612	.74401	.0001	.0001	.0001	.0001
K	.49756	.56736	.57425	.56679	.0011	.0001	.0001	.0001
Mg	.22807	-.15738	-.49288	-.56173	.1569	.3321	.0012	.0002
Mn	.50210	.66275	.73342	.74679	.0034	.0001	.0001	.0001
NH_4	.46946	.56111	.68494	.68549	.0067	.0008	.0001	.0001
O.M.	.47779	.56428	.68004	.71512	.0018	.0001	.0001	.0001

Correlations between individual soil, foliar, microtopographical and tree growth variables were analyzed. First, individual environmental variables or foliar nutrient levels were related to tree growth measurements. One set of environmental variables which were correlated to growth performances were chemical soil properties. Respective soil correlation coefficients and significances are shown by soil layer and chemical soil property for three different tree growth indeces. Note the consistently high positive correlations of soil phosphorous with tree growth variables. Soil potassium, manganese and ammonium also had high positive correlations, especially at lower soil layers, with the three growth performance measures. Soil organic ma tter also moore highly correlated with tree growth at the lower soil layers (6-10½" and 10½-15") than at the upper sample layers (0-3" and 3-6"); this suggests that high nutrient levels and organic matter value s were very important beneath the standard 0-6" sampling zone.

Soil magnesium displayed a negative correlation with tree growth in the lower sample layers. This could have been due to higher clay levels in the poorer plots, which presented more exchange sites for magnesium.

HIGH CORRELATIONS OF SELECTED PHYSICAL SOIL PROPERTIES WITH TREE MEASUREMENTS

TREE MEASUREMENT - TREE VOLUME (o.b.) PER ACRE

Phys. Soil Prop.	Correlation coefficients (r) 0-6" Soil Layer	6-10½" Soil Layer	10½-15" Soil Layer	Probability that rho=0 0-6" Soil Layer	6-10½" Soil Layer	10½-15" Soil Layer
Coarse Silt	.59802	.66493	-----	.0001	.0001	-----
May Soil Moisture	.62729	.41530	-----	.0001	.0077	-----
Bulk Density	-.51662	------	-----	.0006		
March Soil Moisture	*.76	.63346	.49189	*.001	.0084	.0625

TREE MEASUREMENT - AV. HT. OF NINE TALLEST PLOT TREES

Phys. Soil Prop.	0-6"	6-10½"	10½-15"	0-6"	6-10½"	10½-15"
Coarse Silt	.56995	.57222	.59725	.0001	.0001	.0001
Fine Silt	.50533	.34393	.40478	.0009	.0298	.0096
March Soil Moisture	*.73	6 .02021	.50039	*.002	.0104	.0575
May Soil Moisture	.60189	.36297	------	.0001	.0213	-----
Bulk Dens.	-.53746	-----	------	.0003		

TREE MEASUREMENT - AVERAGE d.b.h. (o.b.)

Phys. Soil Prop.	0-6"	6-10½"	10½-15"	0-6"	6-10½"	10½-15"
C. Silt	.53002	.54231	.58284	.0004	.0003	.0001
March H_2O	*.73	.61707	.50670	*.0035	.0109	.0539
May H_2O	.52457	------	------	.0005	------	------
Bulk Dens.	-.50272	------	------	.0009	------	------

Note: * means approximate value

As a general rule, soil physical properties did not correlate as highly with tree performances as did chemical soil properties. Only high correlations were shown in this table. Where values are missing in the table, either this layer was not sampled (as is the case with the $10\frac{1}{2}$-15" soil layer for bulk density and May field moisture determinations) or the correlations were not very high. Of particular interest were the generally higher correlations of physical soil properties to tree variables in the upper (0-6") soil layer as compared to that of lower soil layers. This suggested that good soil infiltrability was very important to good sycamore growth, perhaps more important than soil water percolation deep into the profile. As expected, soil silt and field soil moisture (for March and May) were positively correlated with tree growth assessments. Meanwhile, sycamore trees seem to have preferred a less dense orientation of soil in their surface layer; this was demonstrated by the negative correlations of bulk densities in the 0-6" soil layers with growth performances.

HIGH CORRELATIONS OF FOLIAR NUTRIENT LEVELS WITH TREE GROWTH

	Tree Volume/Acre Cu. Ft. outside bark		Average tree d.b.h. outside bark		Average Height Of Nine Tallest Plot Trees	
Foliar Nutrient	corr.coef. (r)	prob.rho=0	corr.coef. (r)	prob.rho=0	corr.coef. (r)	prob.rho=0
Mn	.63986	.0001	.70470	.0001	.68720	.0001
N	.72557	.0001	.72428	.0001	.70977	.0001
Ca	.85127	.0001	.77645	.0001	.83402	.0001
P	.42700	.0060	.37197	.0158	.40567	.009~~0~~4

HIGH CORRELATIONS OF MICROTOPOGRAPHY WITH TREE GROWTH

Topo Reading						
Net Slope Into Plot	-.49293	.0012	-.59714	.0001	-.59326	.0001
Abs. Slopes Into Plot	-.57673	.0001	-.51941	.0006	-.54227	.0003

The four plant nutrients which, by far, showed the highest correlation between their foliar levels and tree growth performances were manganese, nitrogen, calcium and phosphorous. The correlations involving manganese, nitrogen and calcium were especially high. Because the foliar levels of these three nutrients were so highly correlated with tree growth capabilities, it gave more credence to the rough predictions of foliar nutrient critical values, which were presented earlier. These predicted critical values were 2% for nitrogen, 1% for calcium and .015% for manganese.

Microtopographical factors were correlated with tree growth measurements. In general, they showed that tree growth significantly increased as trees occupied lower relative positions on the landscape. The correlations also suggested that the areas which produced and immediately surrounded better growing trees were generally flatter than those areas which produced and encircled poorer growing trees.

CORRELATIONS OF FOLIAR NUTRIENTS WITH THEIR RESPECTIVE SOIL NUTRIENT IN THE 0-6" SOIL LAYER

Soil and Foliar Nutrient	Correlation coefficient (r)	Prob. rho=0
Manganese	.42742	.0147
Phosphorous	.36590	.0394
Nitrogen N(fol.) with NH_4(soil)	.61312	.0002
Potassium	-.3264	
Calcium	.2792	
Magnesium	-.008656	

The foliar nutrient values were correlated with their respective concentrations in the 0-6" soil layers. High positive correlations would suggest that the amounts of nutrients which were present in the leaves were highly dependent on the concentrations of the respective nutrients in the top six inches of soil. In general, this was found not to have been the case. Phosphorous, manganese and nitrogen foliar levels did display significantly positive correlations with soil nutrient levels. However, only with foliar nitrogen was more than 20% of the respective foliar variation explained by its concentration in the 0-6" soil layer.

Soil potassium (0-6" layer) and foliar potassium were, surprisingly, negatively correlated. This was probably due to two factors: first, the high levels of potassium in all of the soils tested; and secondly, potassium uptake did not seem to have been as adversely affected by poor moisture relations as was uptake of some other nutrients.

Soil calcium (0-6" layer) and foliar calcium had a moderate positive correlation, but this correlation was not statistically significant at the 5% significance level.

Soil magnesium (0-6" layer) and foliar magnesium showed virtually no correlation either positive or negative. The lack of a correlation was not surprising, since magnesium uptake seemed to have been highly affected by influences of calcium ions.

CORRELATIONS OF SELECTED PHYSICAL SOIL PROPERTIES AND MICROTOPOGRAPHICAL DETERMINATIONS WITH THE MOST GROWTH-RELATED FOLIAR NUTRIENTS

Foliar Nutrients

Phys. Prop. or Topo	Manganese		Phosphorous		Nitrogen		Calcium	
	cor.coef. (r)	prob. rho=0	cor.coef. (r)	prob. rho=0	cor.coef. (r)	prob. rho=0	cor.coef. (r)	prob. rho=0
Silt 0-6"	.28922	.0703	.25027	.1193	.60817	.0001	.49100	.0013
May H_2O 0-6"	.26505	.0984	.34787	.0281	.51618	.0007	.64246	.0001
May H_2O 6-10½"	.12131	.4559	.29226	.0672	.35920	.0228	.47362	.0020
Bulk(0-6") Density	-.34197	.0308	-.07397	.6501	-.40062	.0104	-.52151	.0006
Org.(0-6") Matter	.38684	.0137	.32370	.0416	.47836	.0018	.63051	.0001
Net slope Into Plot	-.48883	.0014	-.41736	.0074	-.34069	.0315	-.48276	.0016

Several important correlations existed between soil physical properties and foliar nutrient levels. Percent soil silt (0-6" layer) values were highly positively related to foliar nitrogen and calcium levels. This was probably due to improved soil structure and moisture relations in the soils with higher silt percentages. Field moisture determinations taken during a dry condition in mid-May showed some relationships to foliar nutrient levels. Foliar calcium, nitrogen and phosphorous had significant, positive correlation to May moisture values. This suggested the importance of moisture relations to plant uptake.

Significant negative correlations were also found between soil bulk density (0-6" layer) and foliar manganese, nitrogen and calcium. Most of these correlations developed because of the low bulk densities (in 0-6" soil layer) in excellent plots. Therefore, these negative correlations would probably not have existed if excellent plots were deleted in the analysis procedures.

Soil organic matter percentages correlated with foliar nutrient levels in about the same manner as did soil silt and May moisture determinations. Therefore, foliar nitrogen and foliar calcium were the foliar nutrients with the most positive correlations to this soil property determination. Foliar nutrient levels showed many significant correlations to soil physical properties.

Also, note the relatively high negative correlations between foliar nutrient levels and net slopes into plot centers. This reflected the better nutrient accumulation and moisture availability on lower relative topographical positions.

CORRELATION OF NET SLOPE INTO PLOT WITH SELECTED SOIL VALUES

	Soil Phosphorous 0-6" layer		Soil O.M. 0-6"		% Soil Silt 0-6"		May Soil H_2O 0-6"	
	corr.coef. (r)	prob. rho=0	cor.coef. (r)	prob. rho=0	cor.coef. (r)	prob. rho=0	cor.coef. (r)	prob. rho=0
Net slope into plot	-.35802	.0442	-.48690	.0014	-.27214	.0894	-.24037	.1352

CORRELATION OF NET SLOPE INTO PLOT WITH SELECTED FOLIAR NUT RIENT VALUES

	Foliar Manganese		Foliar Phosphorous		Foliar Nitrogen		Foliar Calcium	
	cor.coef. (r)	prob. rho=0	cor.coef. (r)	prob. rho=0	cor.coef. (r)	prob. rho=0	cor.coef. (r)	prob. rho=0
Net slope into plot	-.48883	.0014	-.41736	.0074	-.34069	.0315	-.48276	.0016

Net slopes into plot centers were correlated to selected soil and foliar measures. Surprisingly, May moisture levels (in the 0-6" soil layers) were not significantly negatively correlated to net slopes into plot centers. However, soil phosphorous levels (0-6" layers) and soil organic matter determinations (0-6" layers) did show the suspected, significantly negative correlations with net slopes into plot centers. Significantly negative correlations to these microtopographical determinations were also found for all observed foliar nutrients. These correlation results emphasized the importance of topography.

CORRELATIONS OF SELECTED SOIL PHYSICAL VARIABLES WITH SELECTED SOIL CHEMICAL VARIABLES

Phys. Soil Var.	Soil Phosphorous 0-6"		Soil Potassium 0-6"		Soil Manganese 0-6"		Soil O.M. 0-6"	
	cor.coef.	prob.	cor.coef.	prob.	cor.coef.	prob.	cor.coef.	prob.
Silt 0-6"	.61218	.0001	.75565	.0001	.80771	.0001	.74076	.0001
May H_2O 0-6"	.62879	.0001	.88936	.0001	.67737	.0001	.74033	.0001
May H_2O 6-10½"	.54350	.0013	.76108	.0001	.61396	.0002	.58384	.0001
B. Dens. 0-6"	-.64934	.0001	-.69910	.0001	-.59098	.0004	-.60859	.0001

CORRELATIONS OF SELECTED SOIL PHYSICAL VARIABLES WITH EACH OTHER

Phys. Soil Var.	Percent Silt 0-6"		May Moisture 0-6"		May Moisture 6-10½"		Bulk Density 0-6"	
	cor.coef.	prob.	cor.coef.	prob.	cor.coef.	prob.	cor.coef.	prob.
Silt 0-6"	--------	-----	.75135	.0001	.71638	.0001	-.60999	.0001
May H_2O 0-6"	.75135	.0001	------	-----	.88587	.0001	-.67543	.0001
May H_2O 6-10½"	.71638	.0001	.88587	.0001	------	-----	.66541	.0001
B. Dens. 0-6"	-.60999	.0001	-.67543	.0001	-.66541	.0001	------	-----

Selected soil values highly correlated (either positively or negatively) with tree growth. In general, selected soil variables also showed very high correlations to each other. Very high, positive correlations existed between soil silt (0-6" layer) and each of the observed soil chemical properties (phosphorous(0-6" layer), potassium (0-6" layer), manganese (0-6" layer) and organic matter (0-6" layer)). High positive correlations to this same set of soil chemical variables were also observed for May, "dry" moisture in the 0-6" soil layer and May soil moisture in the 6-10½" layer. Bulk density determinations showed the expected negative correlations to these chemical soil measurements. However, these correlations were more significantly negative than I would have predicted. In fact, the extremely high correlations between all selected physical variables and selected chemical variables were somewhat surprising.

It was also found that selected soil physical variables highly correlated to each other. Percent silt (0-6" soil layer) determinations positively correlated with May soil moisture readings, while they showed negative relationships with bulk density values (0-6" soil layer). May moisture determinations (both for the 0-6" and 6-10½" soil layers) possessed high positive correlations with soil silt (0-6" layer); meanwhile, these same "dry"moisture values showed strong negative associations with bulk density estimates (0-6" soil layer). Many soil physical properties were highly related to each other.

CORRELATIONS OF SELECTED SOIL CHEMICAL VARIABLES WITH EACH OTHER

Chem. Soil Var.	Soil Phosphorous 0-6" cor.coef. (r)	Soil Phosphorous 0-6" prob. rho=0	Soil Potassium 0-6" cor.coef. (r)	Soil Potassium 0-6" prob. rho=0	Soil Manganese 0-6" cor.coef. (r)	Soil Manganese 0-6" prob. rho=0	Soil O. M. 0-6" cor.coef. (r)	Soil O. M. 0-6" prob. rho=0
P 0-6"	-------	-----	.69187	.0001	.64052	.0001	.72442	.0001
K 0-6"	.69187	.0001	------	-----	.73105	.0001	.79082	.0001
Mn 0-6"	.64052	.0001	.73105	.0001	------	-----	.76076	.0001
O.M. 0-6"	.72442	.0001	.79082	.0001	.76076	.0001	------	-----

As with physical soil properties, the soil variables of a chemical nature which were selected for correlation with each other were factors which possessed high correlations with tree growth performances. The resulting correlation determinations found extremely high, positive relationships between all of the selected chemical variables. The tested, chemical soil variables were phosphorous (0-6" layer), potassium (0-6" layer), manganese (0-6" layer) and organic matter (0-6" layer). Only the 0-6" soil layer determinations were used because, in practice, soil samples are normally not taken much below this layer.

CORRELATIONS OF TREE GROWTH MEASUREMENTS WITH EACH OTHER

Tree Growth Var.	Tree Volume per Acre (o.b.) cu.ft.		Diameter of Plot Trees (d.b.h.)		Average Volume Of Nine Largest Plot Trees		Average Height of Nine Tallest Plot Trees	
	cor.coef. (r)	prob. rho=0	cor.coef. (r)	prob. rho=0	cor.coef. (r)	prob. rho=0	cor.coef. (r)	prob. rho=0
Vol/Ac (o.b.)	-------	-----	.94416	.0001	.97522	.0001	.96587	.0001
Aver. d.b.h. (o.b.)	.94416	.0001	------	-----	.91197	.0001	.97325	.0001
Av. Vol. Of Nine Largest Trees	.97522	.0001	.91197	.0001	------	-----	.95696	.0001
Av. Ht. Of Nine Tallest Trees	.96587	.0001	.97325	.0001	.95696	.0001	------	-----

There are several different methods in which to measure tree growth. In general, tree height, diameter and volume are used singularly or in combination to predict the growth of trees. Hopefully, in local stands of approximately equal spacing, these three growth measures will have very high positive correlations with each other for a given species at a given age. These high correlations were found in my study. Especially note that more than 83% (0.91197 times 0.91197 times 100) of the variation of any of the tree growth measurements presented in this table was explained by any other growth determination shown in the table.

REGRESSIONS OF FOLIAR NUTRIENT LEVELS WITH AV. HEIGHTS OF NINE TALLEST PLOT TREES

1. Regression of foliar nutrient levels and their cross-products with average heights of the nine tallest plot trees

# in Model	Foliar Variables or Interactions	B values	r^2
1		a(10.501)	
	FN x FCa	8.3705	.7770
2		a(7.2939)	
	FN x FCa	7.6064	.7922
	FMn x FK	482.10	
8	--------	-------	.9140

2. Regression of foliar nutrients (Mn, P, N, Ca), their [illegible] cross-products, squares, and tri-products with average heights of nine tallest plot trees

# in Model	Foliar Variables or Interactions	B values	r^2
1		a(10.501)	
	FN x FCa	8.3705	.7770
2		a(9.2613)	
	FN x FCa	10.297	
	(FCa)2	(-2.3465)	.7854
3		a(-20.178)	
	FN	8.3429	
	FCa	41.405	
	(FCa)2	-9.3965	.8358
6	-----	-------	.8911

Note: tree volume is in cubic feet/ acre; tree heights are in feet; foliar nutrient levels are in percent of dry foliage weight. copper is not used in the regression process. the letter "F" before a nutrient symbol means the respective foliar nutrient. the letter "a" before a B value means the intercept value. B values are directly across from the variable or interaction that they represent.

REGRESSIONS OF FOLIAR NUTRIENT LEVELS WITH TREE VOLUME PER ACRE (o.b.)

1. Regression of foliar nutrient levels and their cross-products with tree volume per acre (o.b.)

# in Model	Foliar Variables or Interactions	B values	r^2
		a(-205.28)	
1	FN x FCa	348.39	.8255
		a(-11.534)	
2	FN x FCa	359.73	
	FP x FMg	-7263.8	.8323
8	------ --	---------	.9022

2. Regression of foliar nutrient levels, (Mn, P, Mg, Cu) their cross-products, squares and tri-products with tree volume per acre (o.b.)

# in Model	Foliar Variables or Interactions	B values	r^2
		a(-204.28)	.8255
1	FN x FCa	348.39	
		a(-311.37)	
2	FN x FCa	524.93	
	FN x FCa x FMn	-8214.1	.8406
		a(-980.07)	
3	FN x FCa	827.72	
	FN x FCa x FMn	-28765.2	
	FMn	49041.3	.8762
6			.9020

Note: tree volume is in cubic feet/acre; foliar nutrient levels are in percent of dry foliage weight. copper is not employed in determining regression equations because of its very low value and poor predicting ability.

REGRESSIONS OF THE FIVE MOST INFLUENTIAL SOIL VARIABLES ("BIG 5") WITH TREE VOLUME PER ACRE (o.b.)

1. Regression of the "Big 5" and their cross-products with tree vol/ac. (o.b.)

# in Model	Soil Variables or Interactions	B values	r^2
		a(110.13)	
1	P(0-6) x OM(0-6)	37.027	.7661
		a(-892.62)	
2	Db(0-6)	632.15	
	P(0-6) x OM(0-6)	41.598	.7776
		a(-853.95)	
3	W(0-6)	69.072	
	P(0-6) x W(0-6)	-3.1252	
	P(0-6) x Db(0-6)	70.076	.8214
8			.8594

2. Regression of the "Big 5", their squares, cross-products and tri-products with tree vol/ac. (o.b.)

# in Model	Soil Variables or Interactions	B values	r^2
		a(68.742)	
1	P(0-6) x OM(0-6) x Db(0-6)	27.947	.7943
		a(12.832)	
2	P(0-6) x OM(0-6)	-65.650	
	P(0-6) x OM(0-6) x Db(0-6)	76.415	.8136
		a(-244.64)	
3	(W(0-6))2	2.0304	
	P(0-6) x OM(0-6) x Db(0-6)	53.953	
	P(0-6) x OM(0-6) x W(0-6)	-2.7647	.8314
8	----------------------	-------	.8658

Note: tree volume is in cubic feet/acre; the "Big 5" are soil phosphorous (ppm) (0-6"), soil % silt (wt. basis) (0-6"), soil organic matter (wt. basis) (0-6"), May soil moisture (wt. basis) (0-6"), soil bulk density (g/cm3) (0-6"). the letter "W" stands for May soil moisture. "Db" stands for soil bulk density.

Recall: that soil phosphorous and soil ammonium values that are used in regressions and all other calculations are those obtained under nearly saturated field conditions in early March; levels of these two soil properties were appreciably different in dry, May soils.

REGRESSIONS OF THE FIVE MOST INFLUENTIAL SOIL VARIABLES ("BIG 5") WITH TREE VOLUME PER ACRE (o.b.)

3. Regressions of the natural logarithms of "Big 5", "Big 5's" squares and cross-products with tree vol/ac. (o.b.)

# in Model	Soil Variables or Interactions	B values	r^2
1		a(110.13)	
	P(0-6) x OM(0-6)	37.027	.7661
2		a(-360.47)	
	P(0-6) x OM(0-6)	42.084	
	ln(Db(0-6))	1016.5	.7795
3		a(884.94)	
	P(0-6) x OM(0-6)	44.422	.8020
	ln(Db(0-6))	12814.1	
	(Db(0-6))2	-2672.6	

REGRESSIONS OF THE FIVE MOST INFLUENTIAL SOIL VARIABLES ("BIG 5") WITH AVERAGE HEIGHT OF NINE TALLEST PLOT TREES

1. Regressions of "Big 5" and their cross-products with average height of nine tallest plot trees

# in Model	Soil Variables or Interactions	B values	r^2
1		a(18.499)	
	P(0-6) x OM(0-6)	0.89123	.6915
2		a(4.8484)	
	OM(0-6)	11.030	
	P(0-6) x Db(0-6)	0.83645	.7461
3		a(1.8863)	
	OM(0-6)	13.377	
	Silt(0-6) x P(0-6)	-.0078999	
	P(0-6) x Db(0-6)	1.0952	.7514

Note: tree height is in feet; tree volume is in cubic feet/acre
soil phosphorous (P) is in ppm; soil OM in %(wt.); soil silt in %(wt.); soil Db (B. Density) is in g/cm3; the letters "ln" before a value means the natural logarithm of the value

REGRESSIONS OF THE FIVE MOST INFLUENTIAL SOIL VARIABLES ("BIG 5") WITH AVERAGE HEIGHT OF NINE TALLEST PLOT TREES

2. Regressions of "Big 5", their cross-products, tri-products and squares with average height of nine tallest plot trees

# in Model	Soil Variables or Interactions	B values	r^2
		a(17.536)	
1	P(0-6) x OM(0-6) x Db(0-6)	0.67059	.7125
		a(15.924)	
2	Silt(0-6) x P(0-6) x OM(0-6)	-.0092494	
	P(0-6) x OM(0-6) x Db(0-6)	1.0713	.7262
		a(9.9457)	
3	Silt(0-6) x P(0-6) x OM(0-6)	-.927226 -	
	P(0-6) x OM(0-6) x Db(0-6)	1.5546	
	Silt(0-6) x W(0-6)	.013726	.7507
8	--------------	-------	.8172

3. Regressions of the natural logarithms of "Big 5", and Big 5's" squares, and cross-products with average height of nine tallest plot trees

# in Model	Soil Variables or Interactions	B values	r^2
		a(18.499)	
1	P(0-6) x OM(0-6)	0.89123	.6915
		a(11.364)	
2	(OM(0-6))2	4.4955	.7448
	P(0-6) x Db(0-6)	0.32328	
		a(9.2996)	
3	(OM(0-6))2	5.8308	
	Silt(0-6) x P(0-6)	-.010150	
	P(0-6) x Db(0-6)	1.1428	.7528
8	------ -------	------	.8497

Note: tree height is in feet; soil P is in ppm; soil OM in %(wt.); soil silt in %(wt.); soil Db (B. Density) is in g/cm3 and soil W (May moisture) is in %(wt.)

REGRESSIONS OF SUBSETS OF THE "BIG 5" WITH TREE VOLUME PER ACRE (o.b.)

1. Regressions using soil P (0-6"), silt (0-6"), May moisture (0-6"), and organic matter (0-6"), their squares, cross-products and tri-products against tree volume per acre (o.b.)

# in Model	Soil Variables or Interactions	B values	r^2
		a(110.13)	
1	P(0-6) x OM(0-6)	37.027	.7661
		a(60.858)	
2	(P(0-6))2	-1.4800	
	P(0-6) x OM(0-6)	54.113	.7758
		a(-128.43)	
3	Silt(0-6) x W(0-6)	0.54238	
	P(0-6) x OM(0-6)	59.949	
	Silt(0-6) x W(0-6) x P(0-6)	-.055114	.7972
8	-------------------	---------	.8401

2. Regressions using soil P (0-6"), silt (0-6") and organic matter (0-6"), their squares, cubes, cross-products, tri-products, and products involving all four variables against tree volume per acre (o.b.)

# in Model	Soil variables or interactions	B values	r^2
		a(110.13)	
1	P(0-6) x OM(0-6)	37.027	.7661
		a(20.219)	
2	P(0-6) x OM(0-6)	51.491	
	(P(0-6))4	-.0036461	.7912
		a(89.861)	
3	(P(0-6))4	-.0078053	
	(OM(0-6))4	48.812	
	(P(0-6))2	4.7320	.7974
8	----------	-------	.8752

Note: tree volume is in cubic feet/ acre; soil P is in ppm; soil OM in %(wt.); soil silt in %(wt.); soil Db (B. Density) is in g/cm3 and soil W (May moisture) is in %(wt.)

REGRESSIONS OF SUBSETS OF THE "BIG 5" WITH TREE VOLUME PER ACRE (o.b.)

3. Regressions using soil silt (0-6"), May moisture (0-6"), organic matter(0-6"), and bulk density (0-6", their squares, cross-products, tri-products and products involving all four variables against tree volume per acre (o.b.)

# in Model	Soil Variables or Interactions	B values	r^2
		a(232.99)	
1	Silt(0-6) x OM(0-6) x W(0-6)	.44166	.4669
		a(1065.7)	
2	Db(0-6)	-540.43	
	Silt(0-6) x OM(0-6) x W(0-6) x Db(0-6)	.28517	.4752
		a(1361.0)	
3	Db(0-6)	-740.34	
	Silt(0-6) x OM(0-6) x W(0-6)	-.44606	
	Silt(0-6) x OM(0-6) x W(0-6) x Db(0-6)	.59696	.4768
8	---------------	------	.5964

REGRESSIONS OF SUBSETS OF THE "BIG 5" WITH AVERAGE HEIGHT OF NINE TALLEST PLOT TREES

1. Regressions using soil P (0-6"), silt (0-6"), May moisture (0-6") and organic matter (0-6"), their squares, cross-products and tri-products against average height of nine tallest plot trees

# in Model	Soil Variables or Interactions	B values	r^2
		a(18.499)	
1	P(0-6) x OM(0-6)	.89123	.6915
		a(17.015)	
2	(P(0-6))2	-.044574	
	P(0-6) x OM(0-6)	1.40581	.7052
		a(8.6957)	
3	Silt(0-6) x P(0-6) x OM(0-6)	-.0082384	
	(OM(0-6))2	6.7234	
	P(0-6)	1.6498	.7441
8			.7988

Note: tree volume is in cubic feet/acre; tree height is in feet; soil P is in ppm; soil OM in %(wt.); soil silt in %(wt.); soil Db (B. Density) is in g/cm3 and soil W (May moisture) is in %(wt.)

REGRESSIONS OF SUBSETS OF THE "BIG 5" WITH AVERAGE HEIGHT OF NINE TALLEST PLOT TREES

2. Regressions using soil P (0-6"), silt (0-6"), and organic matter (0-6"), their squares, cross-products and tri-products against average height of nine tallest plot trees

# in Model	Soil Variables or Interactions	B values	r^2
1	P(0-6) x OM(0-6)	a(18.499) .89123	.6915
2	P(0-6) x OM(0-6) (P(0-6))4	a(15.434) 1.3843 -.00012464	.7368
3	(P(0-6))4 (P(0-6))2 OM(0-6)	a(8.4899) -.00023903 .13343 10.085	.7608
8	---------	------	.8241

3. Regressions using soil silt (0-6"), May moisture (0-6"), organic matter(0-6"), and Bulk density (0-6"), their squares, cross-products, tri-products and products involving all four variables against average height of nine tallest plot trees

# in Model	Soil Variables or Interactions	B values	r^2
1	OM(0-6) x W(0-6)	a(18.029) 0.69545	.4685
2	OM(0-6) x W(0-6) W(0-6) x Db(0-6)	a(25.047) 1.0339 -.65577	.4912
3	OM(0-6) x W(0-6) W(0-6) x Db(0-6) Silt(0-6) x W(0-6)	a(26.152) .85295 -.82637 .0086666	.4973
8	---------------	--------	.5407

Note: tree height is in feet; soil P is in ppm; soil OM in %(wt.); soil silt in %(wt.); soil Db (B. Density) is in g/cm3 and soil W (May moisture) is in %(wt.)

REGRESSIONS USING TEN IMPORTANT SOIL VARIABLES ("BIG 10") AGAINST TREE VOLUME PER ACRE (o.b.)

1. Regressions of "Big 10" with tree volume per acre (o.b.)

# in Model	Soil Variables or Interactions	B values	r^2
		a(-46.335)	
1	P(0-6)	66.253	.7234
		a(-343.46)	
2	P(0-6)	47.806	
	OM(0-6)	386.93	.7710
		a(470.25)	
3	P(0-6)	51.323	
	W(0-6)	75.436	
	W(6-10½)	-83.384	.8482
6	--------	-------	.8682

2. Regressions of "Big 10" and their squares with tree volume per acre (o.b.)

# in Model	Soil Variables or Interactions	B values	r^2
		a(-46.335)	
1	P(0-6)	66.253	.7234
		a(-119.90)	
2	P(0-6)	45.701	
	(OM(0-6))2	169.38	.7764
		a(470.25)	
3	P(0-6)	51.323	
	W(0-6)	75.436	
	W(6-10½)	-83.384	.8482
8	-------	-------	.9213

Note: tree volume is in cubic feet per acre; the "Big 10" are soil silt (0-6")(%-wt.), soil P (0-6")(ppm), soil Mn(0-6")(meq/100g), soil K(0-6")(meq/100g), soil NH4 (0-6")(meq/100g), soil O.M. (0-6")(%-wt.), soil C.E.C. (0-6")(meq/100g), May moisture (0-6")(%-wt.), May moisture (6-10½")(%-wt.), and bulk density(0-6")(g/cm3)

REGRESSIONS USING TEN IMPORTANT SOIL VARIABLES ("BIG 10") AGAINST AVERAGE HEIGHT OF TEN TALLEST PLOT TREES (FT.)

1. Regression of "Big 10" with average height of nine tallest plot trees

# in Model	Soil Variables or Interactions	B values	r^2
		a(14.488)	
1	P(0-6)	1.6234	.6767
		a(6.3376)	
2	P(0-6)	1.1174	
	OM(0-6)	10.614	.7324
		a(32.129)	
3	P(0-6)	1.3268	.8145
	W(0-6)	1.9997	
	W(6-10½)	-2.5113	
6	--------	-------	.8465

2. Regression of "Big 10" and their squares with average height of nine tallest plot trees

# in Model	Soil Variables or Interactions	B values	r^2
		a(14.488)	
1	P(0-6)	1.6234	.6767
		a(6.3376)	
2	P(0-6)	1.1174	
	OM(0-6)	10.614	.7324
		a(32.129)	
3	P(0-6)	1.3268	
	W(0-6)	1.9997	
	W(6-10½)	-2.5113	.8145
8	--------	-------	.8674

Note: tree height is in feet; soil P is in ppm, soil OM is in %-wt., soil moisture (W) is in %-wt..

REGRESSIONS USING SIXTEEN IMPORTANT SOIL, FOLIAR AND TOPOGRAPHICAL VARIABLES (BIG 16) AGAINST TREE GROWTH

1. Regression of "Big 16" with tree volume per acre (o.b.)

# in Model	Variables	B values	r^2
		a(-424.95)	
1	FCa	911.76	.7734
		a(-898.06)	
2	FN	353.21	
	FCa	712.02	.8507
		a(-743.42)	
3	FN	278.80	
	FCa	514.34	
	P(0-6)	22.645	.8783
8	------	--------	.9250

2. Regression of "Big 16" with average height of nine tallest plot trees

# in Model	Variables	B values	r^2
		a(4.9932)	
1	FCa	22.551	.7371
		a(-7.4564)	
2	FCa	17.294	
	FN	9.2947	.8205
		a(-3.8956)	
3	FCa	14.483	
	FN	8.8662	
	Net Slope	-2.0482	.8628
8	--------	-------	.9347

Note: tree height is in feet; tree volume is in cu. ft./acre; "Big 16" contains soil variables- silt (0-6), P (0-6")(ppm), K (0-6"), Mn (0-6"), NH4 (0-6"), O.M. (0-6"), C.E.C. (0-6"), May moisture (0-6"), May moisture (6-10½"), (0-6") soil moisture at one atmosphere of tension, and bulk density (0-6")
foliar variables- manganese(FMn), phosphorous(FP), nitrogen(FN), and calcium(FCa)(%-wt.)
microtopographical variable- net slope into the plot centers.
variables are in the following units: for soils, P(ppm), K(meq/100g), Mn(meq/100g) NH4(meq/100g), OM(%-wt), CEC(meq/100g), May moisture(%-wt), moisture @ 1 atm. tens.(%-wt), B.dens.(%-wt); foliar variables are all on %-wt. basis; slope-% basis

REGRESSIONS OF THE "BIG 5" SOIL VARIABLES WITH OTHER TREE GROWTH DETERMINATIONS

1. Regression of "Big 5" with "Theoretical" tree volume per acre (o.b.)

# in Model	Variables	B values	r^2
		a(-78.815)	
1	P(0-6)	80.728	.7435
		a(-335.67)	
2	P(0-6)	61.864	
	W(0-6)	33.562	.8056
		a(-432.63)	
3	P(0-6)	56.565	
	W(0-6)	25.276	
	OM(0-6)	208.84	.8114
5			.8143

2. Regression of "Big 5" with "Theoretical" tree volume per acre (i.b.)

# in Model	Variables	B values	r^2
		a(-214.36)	
1	P(0-6)	74.200	.7455
		a(-446.72)	
2	P(0-6)	57.134	
	W(0-6)	30.361	.8058
		a(-534.70)	
3	P(0-6)	52.325	
	W(0-6)	22.842	
	OM(0-6)	189.51	.8115
5	------	-------	.8147

Note: tree volume is in cubic feet per acre; "Big 5" contains soil silt(0-6"), soil P (0-6")(ppm), soil May moisture (dry)(0-6")(%-wt.), soil organic matter (0-6"), soil bulk density (0-6")
in determinations of theoretical tree volumes per acre, the average plot tree volume is substituted for any missing plot trees

REGRESSIONS OF THE "BIG 5" SOIL VARIABLES WITH OTHER TREE GROWTH DETERMINATIONS

3. Regression of "Big 5" with actual tree volume per acre (i.b.)

# in Model	Variables	B values	r^2
1	P(0-6)	a(-164.34) 60.996	.7316
2	P(0-6) OM(0-6)	a(-435.17) 44.181 352.70	.7787
3	P(0-6) OM(0-6) W(0-6)	a(-435.31) 43.040 223.05 13.027	.7884
5	------	--------	.8000

4. Regression of "Big 5" with average height of all plot trees

# in Model	Variables	B values	r^2
1	P(0-6)	a(12.410) 1.4965	.6695
2	P(0-6) OM(0-6)	a(4.9985) 1.0363 9.6522	.7232
3	P(0-6) OM(0-6) Db(0-6)	a(-6.2400) 1.0809 10.407 6.6197	.7255
5	-------	-------	.7303

Note: tree volume is in cubic feet per acre; tree height is in feet; soil P is in ppm; soil OM is in % by weight; soil bulk density is in g/cm3; soil moisture (W) is in % by weight.

REGRESSIONS OF THE "BIG 5" SOIL VARIABLES WITH OTHER TREE GROWTH DETERMINATIONS

5. Regression of "Big 5" with average diameter (d.b.h.)(o.b.) of plot trees

# in Model	Variables	B values	r^2
		a(1.3561)	
1	P(0-6)	.21585	.6229
		a(.29874)	
2	P(0-6)	.15021	
	OM(0-6)	1.3769	.6718
		a(.37700)	
3	P(0-6)	.15119	
	OM(0-6)	1.5156	
	Silt(0-6)	-.0059300	.6725
5	--------	---------	.6729

6. Regression of "Big 5" with average volume (o.b.) of nine largest plot trees

# in Model	Variables	B values	r^2
		a(-.39279)	
1	P(0-6)	.23813	.7487
		a(-1.1602)	
2	P(0-6)	.18176	
	W(0-6)	.10027	.8128
		a(-1.4547)	
3	P(0-6)	.16567	
	W(0-6)	.075108	
	OM(0-6)	.63432	.8190
5	-------	------	.8252

Note: average volume is in cubic feet/tree; average diameter is in inches per tree; soil P is in ppm; soil moisture (May-dry) is in % by weight; soil organic matter is in % by weight; soil silt is in % by weight.

REGRESSIONS

The regression procedure which I used in all my calculations was the MaxR type procedure. This method allowed for models with the highest "r^2" to be developed. As previously mentioned, the two most important growth indicators were tree volume per acre (o.b.) and average height of the nine tallest plot trees. Therefore, one of these two factors was used as the dependent variable in most of the regressions. The independent variables included foliar nutrient levels, soil determinations and topographical influences, either singularly or in combination.

Foliar nutrient variables were regressed against each of the two most significant tree growth measurements.(pgs. 72-73) The foliar nitrogen-foliar calcium cross-product was found to be a very good growth predicting variable. About eighty percent of the growth variability was explained by this interaction.

In developing soil prediction equations, I almost exclusively used soil properties in the top six-inch layer of soil. The main reason for this was because, in practice, few soil samples are taken much deeper than this layer. However, especially with chemical soil properties, variables in deeper soil layers generally correlated very highly with growth. The five most influential soil variables of the 0-6" soil layer ("Big 5") were correlated with the two major tree growth variables.(pgs. 74-75 The "Big 5" soil variables were phosphorous (ppm), silt (%-wt.), organic matter (%-wt.), May moisture (%-wt.) and bulk density (g/cm3). The phosphorous-organic matter cross-product was an important growth predicting variable. This interaction explained about 69 to 77% of the growth variability. Bulk density generally entered these equations next; however, the small amount of prediction information which it provided did not justify the lengthy tenure required to take and process bulk density samples. Soil silt and moisture determinations also slightly increased the growth prediction capabilities. In an attempt to increase conformity, the natural logarithms of these soil variables were also employed; however, they did not seem to increase growth predictabilities.

Different subsets of the "Big 5" were regressed against the two principal tree growth measures.(pgs. 77-79) Because of the time required for its sampling and processing, bulk density was deleted from the "Big 5". About the same growth predictability resulted after this deletion as existed before it. In order to further simplify sampling, May moisture was also deleted from the "Big 5". The main reason for this deletion was because of the difficulty in finding suitable sample periods which directly correspond to the conditions in my study. This deletion also did not substantially affect growth predictability. When phosphorous and organic matter were both in the regression process, their cross-product was the most influential, singular variable. When phosphorous was removed as a variable, a large drop in growth predictability followed. For three variable models, less than 50% of the growth variability was explained by the other four soil factors.

The number of soil properties employed in regressions was expanded to ten.(pgs. 80-81) It was thought that some important variable interactions within these ten soil factors may have substantially improved the models. The ten important soil variables ("Big 10") included the soil factors of "Big 5" plus manganese (0-6" layer), potassium (0-6" layer), ammonium (0-6" layer), cation exchange capacity (0-6" layer) and May moisture (6-10½" layer). Notice that with these, regressions, cross-products, tri-products, cubes, etc. were not employed as they were often employed in the regression processes ith "Big 5".

The most significant finding was that the soil phosphorous variable (0-6" layer) was a very good growth predicting factor, by itself. Alone, it explained between 67 and 73% of the variability in both of the two most important growth predictability indeces. Again, organic matter was s hown as a significant variable which should be determined. "Dry" soil moisture was also fairly important.

In order to use important soil, foliar and topographical variables together in the regression process, eleven soil factors, four foliar variables and one microtopographical variable were employed.(pg. [illegible]) The "Big 16" variables were as follows: the "Big 10" soil variables plus the soil moisture at one atmosphere of tension in the 0-6" soil layer, foliar manganese, foliar phosphorous, foliar nitrogen, foliar calcium and net slope into the plot centers. No squares, cross-products or other pre-equation interactions were performed on these variables. Foliar levels of calcium and nitrogen were very important in the resulting prediction equations. Soil phosphorous (0-6" layer) or net slope into plot centers was also shown in MaxR regressions with three variables in the models.

So far, all regressions have had either tree volume per acre (o.b.) or average height of the nine largest plot trees as the dependent variable. However, several other tree growth determinations were also made. Recall that tree growth determinations generally had extremely high correlations to each other. Therefore, regressions of these other growth measurements with soil, foliar or topographical variables should have resulted in similar variables being employed in the equations at similar scales. This was found to be the case for regressions of the "Big 5" variables with each of the other growth indeces.(pgs.) Notice the expected high relationships of soil phosphorous values (0-6" layer). Organic matter (0-6" layer) and May soil moisture (0-6" layer) also frequently entered in prediction models containing two or three variables.

IV. Appendix-statistics

Normal Treatment Design

All soil, foliar, topographical and growth variables were treated under the normal treatment design, except for bulk density determinations which were treated under a nested design.

For the normal treatment design, the performance classes (either excellent, good, fair or poor) were designated as the treatments. The plot values for a given variable were designated as the observations. Performance class means and variances were found by standard procedures. The formula for calculating a performance class mean for a given variable is $\frac{\sum_i x_i}{n}$ where x is a variables' observation within the performance class and n is the number of sampled plots (observations) in the performance class. Similarly, the variability within a given performance class, is $\frac{\sum_i (x_i-\bar{x})^2}{n-1}$

The Duncan's Fittness of Fit test was used to determine significant differences between treatment (performance class) means. To perform this test,

1) Rank the treatment means.

2)Look up the "Q" value which corresponds to the number of means between and including the two being compared, and using the degrees of freedom (D.f.) for MSE

3)Calculate the error sum of squares by the formula $\sum_i(\sum_j(x_{ij}-\bar{x}_i)^2)$

4)Calculate the mean square error (MSE) by dividing the error sum of squares by the degrees of freedom for MSE (#obs. minus # trts.)

5)Take the value $Q\sqrt{\frac{MSE}{n}}$ as the comparison number, where n is the number of observations in a given treatment(performance class).

6)Compare the largest and smallest means. If they are significantly different (I used an alpha value of .05), then compare the largest to second smallest, etc. After comparing the largest mean to all the rest, compare the second to largest mean to the smallest mean then to next to smallest and so on. No difference will be declared significant if it is contained between two means which were previously declared not to be significantly different.

Nested Study Design

Four, soil bulk density samples were taken for each plot for each of the two sample layers (0-6" and 6-10½"). Therefore, the sources of variation were performance classes, plots within performance classes and finally determinations within plots.

Four other soil studies, May moisture, August moisture, March penetrometer and August penetrometer, also had some replications performed for plot-layers. However, either insufficient replications or estimated values did not allow for adequate predictions of plot variability; therefore the average plot-layer determinations were used in a normal treatment design framework.

For the nested design, the basic equation is

$$Y_{ijk} = M + A_i + B_{ij} + E_{ijk}$$

where Y_{ijk} is an individual observation

M is the overall mean

A_i is the contribution due to the treatment (performance class)

B_{ij} is the contribution due to the plot within a treatment

E_{ijk} is the contribution due to an observation within a plot, which is within a treatment.

The treatment (perf. class) sum of squares was calculated by

$\text{Trt. SSq} = \sum_{i=1}^{4}\left(\frac{(\text{TRT. TOTAL}_i)^2}{p_i}\right) - CT$ where p is the total number of observations within the respective treatment class; CT is the correction term

The correction term (CT) is calculated by CT = $\frac{(\text{Total value of all obs.})^2}{q}$

where q is the total number of observations taken.

The plot sum of squares was calculated by,

$$\text{Plot SSq} = \sum_i \left(\frac{(\text{PLOT TOTAL}_i)^2}{r_i} \right) - \text{TRT SSq} - \text{CT}$$

where r_i is the number of observations in the respective plot.

The determination sum of squares (error term for plot ssq) was calculated by:

$$\text{Deter SSq} = \sum_i (\text{each observation}_i)^2 - \text{Trt. SSq} - \text{Plot SSq} - \text{CT}$$

The mean square values were calculated by dividing the "SSq" values by their respective degrees of freedom.

Bulk Density for the 0-6" soil layer,

ANOVA table

Source	df	SSq	MSq	EMSq
Trt (P.C.)	3	.37	.123	$\sigma^2 + n\sigma_B^2 + nb\sigma_A^2$
Plot	36	.68	.0189	$\sigma^2 + n\sigma_B^2$
Deter (obs)	118	.92	.0078	σ^2
Total	157	1.97		

where σ^2 is the variance of observations

σ_B^2 is the variance of plots

σ_A^2 is the variance of treatments

n is the number of observations in a plot

b is the number of plots in a trt.

Tests of significance: for trt signif., calc. $F^{3}_{36} = 6.51^*$

for plot signif. calc. $F^{36}_{118} = 2.42^*$

since there is a significant influence by treatments, the variability due to treatments (σ_A^2) can be estimated. σ_A^2 (est.)=.0026

Since there is a significant influence by plots, the variability due to plots (σ_B^2) can be estimated. σ_B^2 (est.)=.0028

Bulk Density for the 6-10½" soil layer,

ANCVA table

Source	df	SSq	MSq	EMSq
Trt (P.C.)	3	.027	.009	$\sigma^2 + n\sigma_p^2 + nb\sigma_t^2$
Plot	34	1.091	.0321	$\sigma^2 + n\sigma_p^2$
Deter(Obs)	112	.479	.00428	
Total	149			

where σ^2 is the variance of observations

σ_p^2 is the variance of plots

is the variance of treatments

n is the number of observations in a plot

b is the number of plots in a trt.

Tests of significance: for trt. signif., calc $F^{3}_{34} = .280^{n.s.}$

for plot signif., calc $F^{34}_{112} = 7.50^{*}$

since there is a significant influence by plots, the variability due to plots (σ_p^2) can be estimated. σ_p^2 (est.) = .00705.

Correlations

Correlations were performed in order to determine relationships between two-variable sets.

The general equation used was : r= corr. coef. = $\dfrac{\sum((x_i-\bar{x})(y_i-\bar{y}))}{\sqrt{\sum(x_i-\bar{x})^2)(\sum(y_i-\bar{y})^2)}}$

where x is one variable and y is the other variable. To test for significance, (r-0) is related to the appropriate rho (p) value.

Regressions

The MaxR regression procedure was used: B using matrices, the basic equation for finding the Beta matrix ($\underline{B}$) is

$$\underline{B} = (x'x)^{-1}(x'y)$$

where x is the matrix of independent variables

y is the matrix of dependent values

x' means x transpose

$(x'x)^{-1}$ means the inverse of $(x'x)$

The proportion of the y's variability which is explained by the set of x's is r^2.

by using matrices again, $$r^2 = \frac{\underline{B}'(x'y) - \left(\frac{(\Sigma Y_i)^2}{n}\right)}{Y'Y - \left(\frac{(\Sigma Y_i)^2}{n}\right)}$$

where $\underline{B}$ is the set of Beta values (matrix form)

x is the matrix set of independent values

y is the dependent values (matrix form)

n is the number of plots (obs.)

y_i is an individual y value

V. Abstract

Sycamore (Platanus occidentalis) growth was related to soil, foliar and topographical factors in a 47-acre plantation. The study area was in the coastal plain of northern Alabama. The soils were derived from limestone-based material and contained high percentages (37-52%) of silt. Most of the soils of the study area developed from upland (residual) parent material; however, some of the depressions within the plantation probably had old terrace alluvium as their most recent parent material.

The better plots occupied the depressional and lower side slope areas, while the poorer-producing plots were situated on the high flat or side slope positions. Even the "fair" plots (average dominant tree height of 25 feet after seven years) usually were on areas of net accumulations of moisture from the surrounding areas.

As with topographical positions, the physical soil properties of the higher site-index plots were also somewhat distinctive from those of poorer quality areas. On the average, the superior growing plots had more silt in their 0-15" soil layer and less clay in their 6-15" soil layer. In addition, under March and May field conditions, the better plots held more available water (0-15" sample layer) than did their counterparts. Furthermore, the very best growing plots (plots in the excellent performance class) averaged less dense soil material in their surface (0-6" layer) than did plots of other performance classes.

Soil chemical properties were also highly related to sycamore growth. Soil organic matter,phosphorous and manganese levels were highly, positively related to growth for all tested soil layers. Soil magnesium was negatively related to tree growth in the 6-15" soil layer. These results suggested that organic matter may have been more effective in pro-

viding exchange sites for manganese than for magnesium; conversely, clay may have been more efficient in providing exchange sites for magnesium than for manganese.

As with soil and topographical factors, foliar nutrient levels also showed important relationships to growth of this hardwood species. Foliar calcium, nitrogen and manganese levels possessed strong, positive relationships to tree growth. On the basis of these sycamore field tests, rough critical foliar levels of these three nutrients were developed. They are as follows: nitrogen-2%, calcium-1% and manganese-.015%.

In general, foliar nutrient values did not strongly relate to their respective soil nutrient levels (in 0-6" soil layer). Only in relating the nitrogen levels (foliage) with the ammonium values (soil) was more than 20% of a foliar variable's variability explained by its respective soil variable (0-6" layer). In fact, potassium's foliar levels negatively related to their soil values.

In contrast, selected soil variables highly related to each other, as a general rule. About 80% of the variability in soil potassium (0-6" layer) values was explained by May, "dry" moisture readings (0-6" layer). Most relationships between selected soil variables were such that 40% to 60% of the variability of one property was explained by another factor.

Growth-predicting models were constructed by use of the MaxR regression procedure. The foliar nitrogen-foliar calcium cross-product explained about 80% of the growth variability. Meanwhile, the soil phosphorous-organic matter (for both, in the 0-6" soil layer) cross-product accounted for about 74% of the variability in growth. Many different prediction equations for growth are shown in the paper for one, two and three variable models. Topographical factors and other soil and foliar variables were also involved in regression equations. In this study, sycamore growth showed some high relationships to soil, topographical and foliar conditions.