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To the Graduate Council:

I am submitting herewith a thesis written by George Samuel Foster, Jr., entitled "Variation in American Sycamore (Platanus occidentalis L.) On the Western Highland Rim of Tennessee." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Forestry.

Eyvind Thor

Eyvind Thor, Major Professor

We have read this thesis and recommend its acceptance:

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VARIATION IN AMERICAN SYCAMORE (*PLATANUS OCCIDENTALIS* L.) ON THE WESTERN HIGHLAND RIM OF TENNESSEE

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

George Samuel Foster, Jr.

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ABSTRACT

The objective of the study was to evaluate natural variation in specific gravity, fiber length, total extractives, and rooting ability of mature stem cuttings of American sycamore (Platanus occidentalis L.) growing on upland sites on the western Highland Rim in Middle Tennessee. Twelve upland trees were selected which had a minimum age of 12 years at breast height; for comparison purposes, an equal number of bottomland trees were selected which were also at least 12 years old at breast height. The upland trees were all located on disturbed sites with acid to highly acid soils.

The first 12 years growth was analyzed for each tree by taking two 11 mm increment cores at breast height (from opposite sides of each tree) and dividing the first 12 increment rings from the pith into six two-year wood segments.

The between-site difference was significant for all six wood segments for fiber length and for most of the two-year segments for total extractives, but was generally non-significant for specific gravity. Bottomland trees had longer fibers than trees from upland sites with the between-site variation accounting for about 34 percent of the total variation. Extractives in the upland population averaged 3.7 percent of the unextracted specific gravity but only 3.1 percent in the bottomland population.

Among-tree differences were significant for unextracted and extracted specific gravity and fiber length for all six two-year wood segments and for total extractives for the first three segments. This variation accounted for about 50 percent of the total variation for unextracted and extracted specific gravity, 38 percent of the total variation in fiber length, and 31 percent of the total variation in the first three segments for extractives.

Fiber length and extracted specific gravity increased significantly with age of the two-year segments for both populations; whereas extractives increased significantly with age for the bottomland population only. In the upland population, age accounted for 50 percent of the variation in fiber length, 16 percent of the variation in extracted specific gravity, and only 1 percent of the variation in extractives. Extracted specific gravity was significantly correlated with radial growth for the upland population ($r = 0.29$) and with fiber length for both the upland ($r = 0.43$) and the bottomland populations ($r = 0.27$).

On the upland site, different trees produced significantly different numbers of rooted stem cuttings. The percentage of rooted cuttings ranged from 83 to 8 percent. Trees which produced greater numbers of rooted cuttings also had a significantly higher number of main roots and significantly longer main roots per cutting. In another experiment using four mature sycamores, five different hormone treatments, and a control applied to girdled cuttings, a significant treatment effect was observed. Of the five treatments, only two (1 percent IAA and 0.8 percent IBA) surpassed the control in number of rooted cuttings.

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CHAPTER I

INTRODUCTION

American sycamore (*Platanus occidentalis* L.) is a native hardwood species which has gained much attention by foresters in the United States in recent years. This attention is due to its fast growth, good wood qualities for pulp and paper production, and large natural range. American sycamore may reach the largest diameter of any American hardwood, sometimes exceeding 10 feet (Betts, 1945).

The range of American sycamore extends from southern Maine to northern Florida and from the Atlantic coast to the Great Plains. It occurs naturally in every state east of the Great Plains except Minnesota. On its western extremes it is found in southeastern Nebraska and the eastern parts of Kansas, Oklahoma, and Texas. Isolated pockets of naturally occurring American sycamore appear in northeastern Mexico (Little, 1971). Two varieties of *Platanus occidentalis* which are recognized are *Platanus occidentalis* var. *attenuata* Sarg. and *Platanus occidentalis* var. *glabrata* Sarg. (Sargent, 1949). The first variety is apparently intermixed with *Platanus occidentalis* throughout its range and the second variety is common in western Texas.

In the northern part of its range, sycamore is found on sites up to 1,000 feet in elevation; but in the southern parts of the Appalachian mountains it can be found on sites up to 2,500 feet in elevation (Fowells, 1965; McAlpine and Applefield, 1973). American sycamore grows on a wide range of soils although it does best on deep, moist, well-drained soils. It can, however, survive and grow well on dry upland sites such as abandoned upland fields, strip mine spoil banks, and other disturbed sites (Briscoe, 1969; Fowells, 1965; McAlpine and Applefield, 1973). Within its natural range, the average annual temperatures vary from 40 to 70 degrees F (Fowells, 1965; McAlpine and Applefield, 1973).

One advantage to tree breeders and silviculturists interested in sycamore is its ability to regenerate well. This species can be considered to be precocious with some individuals producing seed as early as five years of age. The seeds are light brown achenes borne in a round multiple fruit; one fruit can hold approximately 500 seeds in a good crop year (Briscoe, 1969). The germinative capacity ranges from 19 to 80 percent (Bonner, 1974). Juvenile material also has the ability to regenerate by stem cuttings (Briscoe, 1963; Hare and Cooper, 1974; Hare, 1975; McAlpine, 1966; McAlpine, Hook, and Kormanik, 1972; Nelson, 1957; Nelson and Martindale, 1957; Steinbeck, Klaus, and McAlpine, 1973). American sycamore also sprouts back from the stumps of cut trees; because of this characteristic, research is conducted to determine the feasibility of short rotation culture of sycamore in which the trees are planted at a close spacing and are cut like silage on rotations of less than 10 years (Steinbeck, McAlpine, and May, 1972).

A variety of products are made from American sycamore including furniture drawer sides, wire bound boxes, nailed boxes, veneers for plywood used in making furniture, butcher blocks, and handles for brushes and brooms. In recent years its great potential for fiber products such as paper, particleboard, and wood fiberboard has been realized (Betts, 1945; McAlpine and Applefield, 1973).

This study is the first step in a breeding program for American sycamore as fiber for pulp. The primary objective of this study is to evaluate natural variation in specific gravity, fiber length, extractives, and rooting ability of mature stem cuttings of sycamore trees growing on upland sites on the western Highland Rim in Middle Tennessee. Trees were selected on upland sites because of the need to find trees which will grow fiber on short rotations on these sites; the better sites are used for grazing and row crops so only the poorer upland sites are available for forestry.

Estimates of natural variation are important because of their use in developing selection criteria for this breeding program. Breeding programs of this nature for sycamore are dependent upon the regeneration method which is used; there are certain advantages of vegetative methods such as the greater gain obtained by the use of clonal material.

CHAPTER II

LITERATURE REVIEW

Since this study deals entirely with sycamore which is a diffuse-porous hardwood, the literature review is limited to this group of hardwoods.

I. Wood Properties

Specific Gravity

Wood specific gravity is usually expressed as the oven-dry weight in grams per cc of green volume rather than per cc of oven-dry volume as is the case when using the traditional concept of density. However, wood scientists usually use the term specific gravity to represent the density of wood. In this study, specific gravity is used to refer to bulk density of the wood.

Specific gravity is a measure of the actual cell wall content per unit volume contained in woody tissue. Without this information, the volume of wood may not have much meaning as related to tons of paper which can be produced from it. A small volume of wood with a high specific gravity may actually produce more tons of wood fiber or wood fiber products than a relatively large volume of wood with a low specific gravity.

Because of the positive relationship between specific gravity and tons of fiber products produced, tree breeders have given much attention to variation in specific gravity within and among trees. Most commercially important species of trees have been tested for specific gravity, and the species which are most often used for pulp production have been extensively tested for specific gravity variation within individual trees, among trees, and among ecotypes or geographic varieties within the species.

Heritability estimates for specific gravity have been given by several researchers. Farmer and Wilcox (1966) calculated narrow sense heritability from half-sib progeny tests of cottonwood (Populus deltoides Bartr.) and arrived at an estimate of 0.62. This narrow sense heritability estimate, if combined with sufficient phenotypic variation, would allow for considerable gain when breeding trees for high specific gravity. Inherited differences in the cambial initials among trees of the same species, and the mean specific gravity of entire increments and early and late-wood zones separately have been shown to be heritable. Therefore, if individual trees or stands of trees within a species have superior wood specific gravity, then breeding programs can be established to produce trees with more desirable specific gravity.

Tree breeders have worked for years to learn the pattern of variation of specific gravity in forest trees. This variation may occur at several levels, including variation throughout the natural range of the species, variation between different sites within a certain portion of the total range, variation among individual trees occupying the same stand, and variation within individual trees.

In general, the among-tree component of variation is often larger than the variation which may be associated with geographic races within a species. Thorbjornsen (1961) in his yellow-poplar (Liriodendron tuplipifera L.) study, Farmer and Wilcox (1966) in their cottonwood study, Webb (1964) in his sweetgum (Liquidambar styraciflua L.) study, Lee (1972) and the Annual Report of Cooperative Regional Project S-23 (1976) in their sycamore studies discovered no significant variation in specific gravity among geographic areas within the natural range of each species.

Some researchers, on the other hand, have reported significant variation within the natural range of certain species. Posey (1969) working with cottonwood, McElwee and Faircloth (1966) with water tupelo (Nyssa aquatica L.), Schmitt and Wilcox (1969) with sycamore, Johnson and McElwee (1967) and Hunter and Goggans (1968) with sweetgum all found significant variation in specific gravity among stands within the species range.

Another source of variation which may be important in wood properties of forest trees is variation between different sites within a given region. Evolutionary trends in other species of plants have shown that when there is a great difference between sites on which a species occurs then divergence may occur in the population. This divergence may first lead to the formation of sympatric populations which can still interbreed, but divergence may progress so far that sub-species and finally different species form. Thor and Core (in press) in their work with yellow-poplar found a significant difference in wood specific gravity among trees on upper and lower slope positions. The trees on the upper slope had higher specific gravity than the ones growing on the lower slope. It is highly likely that this difference is due to the site and not the genotype of the trees. In a study with natural cottonwood stands, Farmer and Wilcox (1966) found a small yet significant variation due to transects in locations. They reasoned that this difference was probably due to site differences and their effect on growth of the trees between the different transects. On the other hand, Webb (1964) in a preliminary geographic study of sweetgum did not find a significant difference in the specific gravity of trees on upland and bottomland sites. Thus it can be seen that some studies of forest trees hint at the presence of some variation between sites as to wood properties; but if this variation is present, it usually is a small portion of the total variation and is probably of environmental rather than genetic origin.

Individual or among-tree variation appears to be the largest component of variation present in most species of forest trees. This variation is easily seen and most striking when trees of different parentage are planted together in plantations on uniform sites. The among-tree component of variation is much larger than the within-tree component and is often larger than the variation associated with geographic races within a species. With water tupelo (McElwee and Faircloth, 1966), yellow-poplar (Thorbjornsen, 1961; Taylor, 1968), sweetgum (Webb, 1964; Hunter and Goggans, 1968), cottonwood (Farmer and Wilcox, 1966), and sycamore (Taylor, 1969; Schmitt and Wilcox, 1969; Lee, 1972; and the Annual Report of Cooperative Regional Project S-23 on American Sycamore, 1976), significant variation in specific gravity among-trees-within-stands was observed. In fact, the major amount of the total variation was accounted for by this level of variation.

One study with sweetgum (Johnson and McElwee, 1967) failed to find a significant variation in specific gravity at the tree-within-stand level of variation. Surprisingly, the researchers discovered significant variation only at the stand level of variation. They explained their results as a failure to sample intensively enough at the tree-within-stand level.

From these studies, it can be seen that in diffuse porous hardwoods significant variation is associated with individual trees within a species. In most cases this component accounts for the largest percent of the total variation. This fact is good news for tree breeders interested in improving the wood specific gravity of diffuse porous hardwoods because the selection process can center on selection of superior individuals throughout a large part of the species range.

Variation within an individual tree is the final source which will be discussed in this paper. Since this study deals with within-tree variation at breast height, the variation associated with different heights in the individual tree will be excluded. Taylor (1969) gives an excellent presentation of variation in wood properties of sycamore associated with tree height.

One of the first factors to consider in studying variation of specific gravity within a tree is the presence of several different types of wood commonly recognized in a tree. Three main categories may be discussed at this level which include juvenile versus mature wood, springwood versus summerwood, and heartwood versus sapwood. The portion of wood which is formed at the pith and for several years afterward is referred to as juvenile wood, and the portion of wood which is formed from the juvenile wood out to the cambium is referred to as mature wood. The transition from juvenile to mature wood is abrupt in some species but is more gradual in others. Schmitt and Wilcox (1969) and Lee (1972) noted an increase in specific gravity of sycamore with increasing ring age from the pith. Schmitt and Wilcox (1969) stated that this increase indicated the presence of a juvenile zone of wood; but Lee (1972) felt that since the increase was a gradual transition instead of an abrupt change, there was no distinct juvenile zone of wood near the pith. Jett and Zobel (1975) determined that for sycamore and cottonwood the differences in wood properties between years two and fifteen were quite small, and it does not differ so greatly that it would create difficulties in paper qualities following pulping.

Thorbjornsen (1961) reported a correlation coefficient of 0.731 (significant at the 0.1 percent level) between wood density in the middle section of the increment cores and wood density in the outer section of the increment cores of cottonwood. Lee (1972) in his sycamore study reported a correlation coefficient of 0.557 (significant at the 1 percent level) between specific gravity of wood in the first five years and the specific gravity of the wood in the six through ten years section. From these values, it would seem possible to make an early prediction of specific gravity of mature wood from the specific gravity of the juvenile wood. This prediction could be made with a fair to good degree of accuracy.

Within a single growth ring, specific gravity may vary due to the differences between springwood and summerwood. Generally in hardwood tree species, springwood has a lower specific gravity due to relatively thinner walled cells and the presence of vessel elements; summerwood has a relatively higher specific gravity due to thicker walled cells and the absence of vessel elements. With ring porous hardwood species this difference in specific gravity can be relatively large within a growth ring; but with diffuse porous hardwoods this difference is relatively small. In this study, the changes in specific gravity within a single growth ring are of minor importance because a single estimate of specific gravity will be made for each two-year segment of an increment core.

For many species of trees, the formation of heartwood and sapwood can lead to large differences in specific gravity of the wood in the two areas. A heartwood region is formed near the pith of the tree and continues outward as the tree ages. This formation depends on the species, age of the tree, and on individual tree differences. The remainder of the xylem from the heartwood region outward is referred to as the sapwood. Heartwood formation is generally caused by a buildup of stains and extractives; but as Thorbjornsen (1961) observed with yellow-poplar, may be due entirely to the buildup of stains alone. Since sycamore generally does not develop extensive heartwood and the trees selected for this study may not be old enough for any heartwood development, the differences in specific gravity due to heartwood and sapwood formation will not be considered as a source of variation.

The relationship between specific gravity and number of rings from the pith has been researched by several authors. For sycamore, Taylor (1969), Schmitt and Wilcox (1969), and Lee (1972) report at least a slight increase in specific gravity from the pith to the cambium. In 12 stands of sycamore this increase in specific gravity with age was significant (Lee, 1972). McElwee and Faircloth (1966) reported that with water tupelo the specific gravity was lowest near the pith and increased rapidly until years 11 through 20 after which it leveled off. This same trend was also found in sweetgum (Webb, 1964) and in yellow-poplar (Taylor, 1968). Thorbjornsen (1961) reported an increase in density from the inner core to the outer wood (30 years) in yellow-poplar.

Much controversy has occurred over the effect of growth rate on wood properties. The effect of growth rate on specific gravity is of special interest; if there is no relationship or a positive relationship, then any possible means for growing wood faster could be pursued. Taylor (1968) and Thor and Core (in press) found no significant relationship between growth rate and specific gravity in yellow-poplar. Similarly, Webb (1964) discovered no relationship between specific gravity and growth rate in sweetgum; and for sycamore this finding also seems to hold true (Taylor, 1969; Lee, 1972). Saucier and Ike (1969a) used sycamore in a fertilizer study and found no decrease in specific gravity of the wood while there was a highly significant increase in growth rate.

In a study of sweetgum in Alabama, Hunter and Goggans (1968) did find a significant and positive correlation between growth rate and specific gravity, but the correlations were so small (0.13 for the first 10 years interval and 0.10 for the second 10 years interval) that they were almost negligible. From a fertilizer and thinning study using sycamore, Saucier and Ike (1969b) concluded that growth rate and specific gravity were positively correlated; they did not, however, state whether this correlation was significant.

From these studies with diffuse porous hardwoods, it appears that growth rate is either independent of specific gravity or at the most is positively correlated with it. This finding is truly encouraging to tree breeders and silviculturists. Through genetics and silvicultural treatments, growth rate of trees can be improved without degrading wood specific gravity.

Extractives

The extraneous material which may occur in the cell walls and within the cell lumen of many species of trees and can be removed with organic solvents is collectively termed extractives. They are usually either infiltrated into the cell walls or they may be present as surface deposits or plugs in cell lumina. An extremely wide range of organic compounds is represented in extractives. Two of the main groups of these extractives which are of economic importance are the wood resins and the polyphenols. The wood resins are the source of tall oil, sulfate turpentine, and rosin. Occurring in both angiosperms and gymnosperms, the polyphenols include many chemicals such as tannins, anthocyanins, flavones, catechins, and kinos. Some other extractives which are found include gums, tropolones, fats, fatty acids, waxes, and volatile hydrocarbons. In most species of trees, the extractives constitute a very small percentage of the oven-dry weight of the wood. The distinguishing features of wood such as color and odor are due mainly to extractives which are present. In addition to such characteristic features, extractives may lend fungal and insect resistance to certain species of wood. They are related to permeability, specific gravity, hardness, and compressive strength of wood.

The amount and kind of extractives present in wood have been found to greatly affect pulping for paper production (Hillis, 1962):

1. Reduction in yield--When weighing wood for the prediction of pulp yield, the presence of a large amount of extractives will cause an overestimation of pulp yield.
2. Increased chemical consumption--When wood is pulped by the alkaline process, sodium hydroxide is consumed by the reaction with the different types of extractives in the wood. This reaction reduces the amount of alkali available for the delignification process.
3. Inhibition of the pulping reaction--This is related to (a) reduced penetrability, (b) reduced lignin solubility, and (c) liquor decomposition.
4. Increased equipment corrosion--Some extractives speed the corrosion of equipment used in pulp production.
5. Bleaching--Bleaching is sometimes required to remove stains.

The distribution of extractives within trees has been researched rather well for many of the gymnosperm species, but little has been done with angiosperm species because of the relatively low occurrence of extractives. Hillis (1962) stated that old trees generally contain more extractives in the heartwood than do young trees of the same species. However, Thorbjornsen (1961) observed that in yellow-poplar there was no greater amount of extractives in the heartwood than in the sapwood of older trees; he assumed the main difference to be due to the presence of stains in the heartwood. Little research has been conducted with diffuse-porous hardwoods dealing with the occurrence of extractives from the pith to the cambium. In their study of cottonwood and sycamore, Moore and Effland (1974) reported that no outstanding differences were discovered in the extractive content between fast growing juvenile trees and slow growing mature trees. The tannin content of trees of the same species grown in different localities may be different; factors such as climate, soil, and botanical variation may be responsible (Hillis, 1962).

The effect of genetics on extractive production is still not well known, especially in angiosperm species. Hillis (1962) stated that genetic variation may be the cause of differences in polyphenol content in different trees of the same species. The amount of this variation which is genetic and the amount which is environmental is still unknown.

Fiber Length

Fiber length is an important factor in making paper; certain types and qualities of paper depend heavily on fiber dimensions, especially length. In general the longer wood fibers make better quality paper and give it favorable strength qualities. Coniferous species tend to have long tracheids while in comparison the hardwood species tend to have relatively short wood fibers. For this reason, paper makers preferred conifers for their fiber supply. However, in recent years, paper makers began to realize that some hardwood species did indeed have fibers of sufficient length and other dimensions to promote their use as pulpwood.

Tree breeders have done considerable research into the heritability of fiber length. At first they were optimistic about breeding trees for longer fibers; but as heritability estimates started appearing in the literature, they were rather disappointing. Farmer and Wilcox (1966) reported a narrow sense heritability of cottonwood of 0.40 for fiber length. If the phenotypic variations were large, even this relatively low heritability would allow for a good chance for improvement of fiber length. However, this does not seem to be the case. Fiber length tends to have small variation within a species.

As with specific gravity, fiber length seems to vary on several different levels. Variation may occur throughout the entire natural range of a species, between different sites in a certain portion of the range, among individual trees in the same stand, and within individual trees.

In diffuse porous hardwoods, some variation occurs among different stands within the natural range. With sweetgum (Webb, 1964; Johnson and McElwee, 1967), yellow-poplar (Thorbjornsen, 1961), water tupelo (McElwee and Faircloth, 1966), cottonwood (Posey, 1969), and sycamore (Schmitt and Wilcox, 1961; Lee 1972), researchers found significant variation in fiber length among stands. However, none of them were able to determine a trend in this variation, and most of them reported that it accounted for only a small portion of the total variation. At least one team of researchers discovered no significant variation among stands as to fiber length; Wilcox and Farmer (1968) in their cottonwood study found no significant difference in fiber length among the locations which they sampled.

Different sites within a certain part of the natural range of a tree species may also be a source of variation in fiber length. Few reports are available on this type of information. The ones which are available report no significant difference among fiber lengths; or if there is a significant difference, it accounts for a low percent of the total variation. Webb (1964) in his sweetgum study found no significant difference between upland and bottomland sites as to fiber length. Wilcox and Farmer (1968) discovered a significant difference among transects located on different sites, but they stated that it was not a consistent difference and represented only a small amount of the total variation. Thor and Core (in press) reported that in a natural yellow-poplar forest site factors account for only a small percent of the total variation; however, up to 51 percent of the variation in fiber length was related to site factors in yellow-poplar plantations.

As with specific gravity, fiber length variation among-trees-within-stands is probably responsible for a considerable portion of the total variation. Webb (1964) and Johnson and McElwee (1967) in their sweetgum studies, Wilcox and Farmer (1968) in their cottonwood study, McElwee and Faircloth (1966) in their water tupelo study, and Taylor (1969), Schmitt and Wilcox (1969), and Lee (1972), in their sycamore studies all found significant variation among trees in the same stands. Some authors (Wilcox and Farmer, 1968; Webb, 1964) stated that trees-within-stand accounted for most of the total variation. One author reported no significant difference among trees within the same stands; Thorbjornsen (1961) stated that by more intensive sampling of yellow-poplar, it is probable that statistically significant differences among trees would be detected.

The variation in fiber length within an individual tree can be very great in diffuse-porous hardwoods. Researchers who investigated this level of variation (McElwee and Faircloth, 19-6; Johnson and McElwee, 1967; Thorbjornsen, 1961; Lee, 1972) stated that there was a significant variation within individual trees. Thorbjornsen (1961) reported this component to account for 49 percent of the total at 11 years and 90 percent of the total at 31 years. Lee (1972) stated that fibers-within-cores accounted for 84 percent of the total variation. Thus it can be seen that this is the level where most of the total variation appears and not at the among-trees or among-stands levels. This fact plus a possibility for relatively narrow phenotypic variation indicates a very small gain in breeding for longer fibers.

The change in fiber length from the pith outward to the cambium at breast height is well documented for many tree species. Dinwoodie (1961) stated that the general trend is for the fibers in the ring nearest the pith to be very short and to increase in length rapidly outwards for the first few rings, and then the rate of increase starts to decline. For all of the diffuse-porous hardwoods the pattern seems to be the same. Fiber length increases sharply as successive rings from the pith are reached. At about 15 to 20 years of age the fiber length starts to level off. Finally, in overmature trees, the length may actually start to fall. In sycamore, fiber length increases consistently from the pith outward (Jett and Zobel, 1975). Schmitt and Wilcox (1969), Taylor (1969), McElwee, Tobias, and Gregory (1970), and Lee (1972) all reported an increase in fiber length in sycamore till approximately 15 to 20 years of age when it leveled off and eventually started to decline.

It may be possible to predict fiber length in mature wood by measuring the fiber length in juvenile trees. In sweetgum, Johnson and McElwee (1967) determined a correlation coefficient of 0.766 between fiber length at age 15 and fiber length at age 30. Similarly, Wilcox and Farmer (1968) discovered a correlation coefficient of 0.67 between fiber length at age 8 through 10 and fiber length at age 18 through 20.

The effect of growth rate on fiber length has been researched by several authors; in sweetgum (Webb, 1964), cottonwood (Boyce and Kaeiser, 1961), water tupelo (McElwee and Faircloth, 1966), and sycamore (Saucier and Ike, 1969a) no relationship was found between fiber length and growth rate. Saucier and Ike (1969b) did find a positive correlation between fiber length and growth rate in sycamore; thinning increased fiber length slightly while fertilizer application had no effect. In his sycamore study, Lee (1972) found a significant and weakly positive relationship between fiber length and growth rate; the correlation coefficient was 0.134. Similarly, Thor and Core (in press) reported a significant positive correlation between growth rate and latewood fiber length of yellow-poplar on the upper slope position. Therefore, growth rate does not seem to have a strong effect on fiber length in diffuse-porous hardwoods.

The possible correlation between specific gravity and fiber length in trees has been researched for several species. Johnson and McElwee (1967) and Webb (1964) in sweetgum, Thorbjornsen (1961) in yellow-poplar, Schmitt and Wilcox (1969) and Lee (1972) in sycamore, and McElwee and Faircloth (1966) in water tupelo failed to find a significant correlation between specific gravity and fiber length. Therefore it seems that in diffuse-porous hardwoods it will be possible to breed for higher specific gravity without affecting fiber length.

II. Rooting of Mature Hardwood Cuttings

Several factors affect rooting of stem cuttings from trees. Among these factors, some of the more important ones are physiological age of cuttings, treatments used to induce root formation, cutting location on the branch and in the crown where cuttings were obtained, season in which cuttings are taken, and the inherent ability of the tree to form roots on cuttings.

Age

The effect of tree age on the ability of stem cuttings to root may be large; Hartmann and Kester (1975) stated that almost always stem cuttings taken from young or juvenile material will root much more readily than stem cuttings taken from older or mature plants. McAlpine (1966) reported that many studies of rooting in cuttings from species of forest trees showed a sharp reduction in rooting after age two through five and that survival of rooted cuttings declines with increasing age of the tree from which the cuttings were taken. In a yellow-poplar study, McAlpine and Kormanik (1972) noted an average of 22 percent rooting in epicormic branch cuttings (maturity of epicormic branches is questionable) from 33 trees of age 16 through 52; when they tested juvenile stump sprouts of different trees, they found that 61 percent of the cuttings rooted. With sycamore, Hare (1975) found no difference in rooting ability of cuttings taken from 6 and 13 year old trees.

Several explanations have been given by researchers for this age effect. Hartmann and Kester (1975) felt that it may be explained by an increasing production of rooting inhibitors as the plant grows older. Hare (1975) on the other hand felt that this age difference with respect to rooting was largely due to low food reserves in cuttings from older trees.

Treatments

Many different treatments have been tried to induce rooting of stem cuttings from various species of forest trees. The discovery of auxin in the early part of the 1900's provided an excellent substance for propagators to use on tree species which had previously proven difficult or impossible to root. Since that first auxin discovery, several natural and synthetic auxins and other rooting chemicals have been evaluated. The most success in rooting cuttings of tree species has been through treatment with indolebutyric acid (IBA). Rooting of stem cuttings with the aid of IBA has been reported for yellow-poplar (Enright, 1957; McAlpine, 1964; McAlpine and Kormanik, 1972), sycamore (Hare and Cooper, 1974; Hare, 1975), cottonwood (Nelson, 1957), and other diffuse porous hardwoods (Snow, 1939).

Girdling tree trunks and branch tips has also been used to facilitate rooting of cuttings. McAlpine and Kormanik (1972) partially girdled the trunks of several yellow-poplar trees to force epicormic branches to be used as cuttings. Nelson (1957) with cottonwood, and Hare (1975) with sycamore girdled branch tips and treated the girdles with IBA; they later rooted the branch tips and reported nearly 100 percent success.

With easy-to-root species, the juvenile cuttings may be taken and placed either in a mist bed or planted directly in the field. Survival and growth using this technique can approach that obtained with planted seedlings.

Cutting Location

The location from which the cutting is taken in the crown and also along the entire branch can be important. In red maple (*Acer rubrum* L.), the cuttings which were taken from the lower portion of the crown rooted significantly better than the ones taken from the upper portion of the crown (Edgerton, 1944; McAlpine, 1966). Briscoe (1963) in his studies of cottonwood, willow, and sycamore found a highly significant effect due to the position of the cutting along the branch; he found that the basal segment rooted the best. Similarly, Nelson and Martindale (1957) and Hare and Cooper (1974) found that the basal segment of sycamore branches had the highest percentage of rooting. Furthermore, height growth was better for the rooted basal segments (Nelson and Martindale, 1957). Hartmann and Kester (1975) felt that this trend may be due to preformed root initials; these root initials are most abundant at the base of the branch and decrease in number toward the branch tip.

Whether the cutting is taken from a lateral or terminal branch may also be important in hard-to-root species. Lateral branches often root better than terminal branches (Hartmann and Kester, 1975).

Season

The season in which the cuttings are taken is usually important. This is especially true if the species tend to be hard-to-root. Briscoe (1963), in his study of cottonwood, willow, and sycamore, found that rooting response was significantly different when the cuttings were cut and planted in different months of the year. A significant interaction between month of planting and species also occurred. Cottonwood rooted better when cut and planted in November while willow and sycamore rooted better when cut and planted in March. Nelson and Martindale (1957), however, in their sycamore study found that there was no significant difference in survival of cuttings planted in the fall or spring.

Hartmann and Kester (1975) stated that softwood cuttings of some deciduous woody species taken during spring or summer tend to root more readily than hardwood cuttings taken in the winter. The best results are obtained if the cuttings are taken in the early spring as soon as the leaves are fully expanded and the shoots have reached some degree of maturity. This technique would be especially useful with a hard-to-root species or mature material.

Genetic

The relative importance of genetic effects on rooting ability of individual trees within a species has often been neglected. Much has been done to improve the environment used for rooting cuttings, but little has been done to identify individual forest trees which are inherently better for developing roots on cuttings. McAlpine (1966) and Hartmann and Kester (1975) discussed the variation among individuals within a species as to the ability to develop roots on cuttings. Plant progagators often refer to easy-to-root and hard-to-root species or varieties within a species and a large number of clones used by ornamental horticulturists were selected not only for their desirable appearance but also for their rooting ability. This genetic effect is well recognized in several coniferous species but only occasionally has been alluded to in hardwoods (Hare, 1975), and it is seldom directly or purposefully tested. In his work with juvenile red maple, Snow (1939) tested 24 different clones for variation among individual trees and within trees. He found a highly significant difference in rooting response among clones but there was no significant difference among different lots of cuttings from the same tree. Individual tree means varied from 17.5 to 97.5 percent.

CHAPTER III

MATERIALS AND METHODS

I. Selection of Trees

The populations of sycamore trees used in this study are located on the western Highland Rim in Middle Tennessee. The western Highland Rim has as its general boundaries the Tennessee River to the west and the Central Basin to the east (Figure 1). It is a distinct physiographic region in Tennessee.

To be selected for this study, the trees had to be situated on a dry upland site within the Highland Rim physiographic region. The location of the 12 selected upland trees is shown in Figure 2. An upland site is usually a physiographic position where the soils are developed from the underlying rock; the soils located on these positions are often referred to as residual soils. The Highland Rim soils were mainly developed from cherty limestone parent material. This is especially true of the ridges which are occupied mainly by cherty soils. These soils tend to be low in fertility and low in water holding capacity.

The trees also had to meet certain physical criteria. They had to be at least 12 years of age at breast height. Trees were selected at a sufficient distance from each other to assure reproductive isolation, at least 3 miles apart with some being approximately 50 miles apart. This isolation lessens the chance that any of the trees are closely

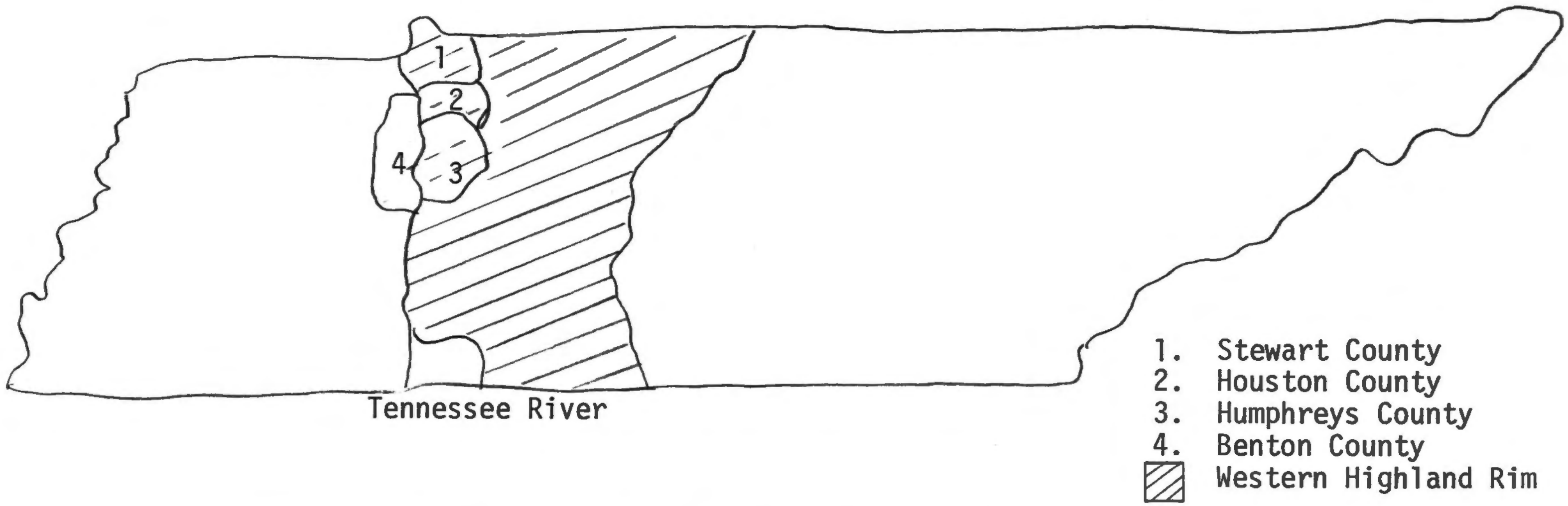

FIGURE 1. Location of the Western Highland Rim Physiographic Region and Stewart, Benton, Houston, and Humphreys Counties in Tennessee.

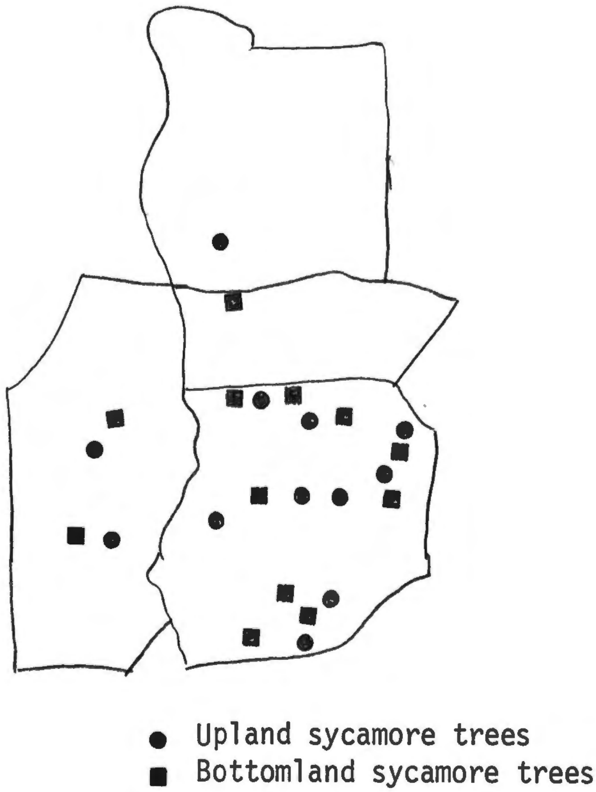

FIGURE 2. Location of the 24 Selected Sycamore Trees in Stewart, Benton, Houston, and Humphreys Counties in Tennessee.

related and will give a better estimate of the total variation within the physiographic region. Eight characteristics of each tree were measured or estimated:

1. Diameter at breast height DBH--Diameter at 4.5 feet above ground level to nearest 0.1 inches.
2. Total height--Height of the main stem from ground level to the top to the nearest 1 foot.
3. Age--Age of tree at 4.5 feet above ground.
4. Stemform--Taper of the tree from the base to top: Good--slight taper; fair--medium taper; poor--great amount of taper.
5. Straightness--Straightness of bole of tree: Excellent--straight; good--slight deviations from straight; fair--not straight.
6. Pruning--Absence of limbs on bole from ground to top of tree: Excellent--live crown approximately 1/3 of total height; good--live crown approximately 1/2 of total height; fair--live crown approximately 2/3 of total height; poor--live crown more than 2/3 of total height.
7. Crown size--Actual radius of crown measured to the average drip line to the nearest foot.
8. Branches--Average diameter of branches: Coarse--average branch diameter 3 inches or more; medium--average branch diameter 2 to 3 inches; fine--average branch diameter 1 inch or less.

This information for the upland trees is summarized in Table 1.

Environmental factors such as soil can often alter the phenotype of trees greatly. Although the upland sycamore trees were selected

TABLE 1. Characteristics of 12 Sycamore Trees Growing on Upland Sites on the Western Highland Rim in Tennessee.

Characteristics	Tree Number											
	I-1	I-2	I-3	I-5	I-7	I-9	I-10	I-13	I-18	I-21	I-22	I-23
DBH (inch)	11.7	7.0	7.5	10.2	6.5	8.6	6.2	7.1	18.0	10.0	10.1	12.1
Total Height (ft)	49	38	44	37	40	52	54	32	56	42	60	51
Age (years)	31	13	20	16	20	13	13	21	17	14	27	17
Stemform (taper)	fair	fair	fair	poor	good	good	good	fair	poor	fair	good	fair
Straightness	good	good	good	good	excell.	good	excell.	fair	fair	good	excell.	good
Pruning	fair	poor	fair	poor	excell.	good	good	fair	poor	poor	good	fair
Crown size (ft)	9.2	10.0	8.1	15.2	8.5	11.0	11.8	10.7	22.0	16.3	8.0	20.0
Branches	coarse	fine	fine	medium	fine	medium	medium	medium	coarse	fine	medium	coarse

primarily for the physiographic position on which they grew, some aspects of the site varied somewhat within these restraints. Using soil surveys (Austin and others, 1953; Odom and others, 1953; Welles and others, 1946; Wildermuth and others, 1958), the soil type was recorded for each site where a selected tree was located (Table 2). Site characteristics such as steepness of slope and position on slope may also account for some of the variation among the selected upland trees.

All of the upland trees are located on disturbed sites such as along roadbanks, old quarries, and power line right-of-ways. None of the upland sycamores were growing in a closed forest environment.

Sycamore trees growing on distinctively bottomland sites were chosen for comparison with the upland trees. The first criterion for the selection of these trees was location on a bottomland along a stream or river. These trees were located as near the upland trees as possible but at a distance which would provide reproductive isolation. Their location is shown in Figure 2, page 26. Other than site, these trees met the same selection criteria as the upland trees; a summary of their characteristics is presented in Table 3.

II. Wood Samples

Two 11 millimeter increment cores reaching from the bark to the pith were taken from opposite sides of each tree. It has been shown with sycamore that two cores taken at breast height provide samples which accurately estimate the specific gravity and fiber length for the entire tree (Lee, 1972). Upon extraction from the tree, each core was properly marked for identification and placed in a plastic tube and

TABLE 2. Soil Phase Associated with 12 Selected Sycamore Trees on Upland Sites.

Tree Number	Soil Phase
I-1	Bodine cherty silt loam
I-2	Bodine cherty silt loam, slope phase
I-3	Bodine cherty silt loam, slope phase
I-5	Bodine cherty silt loam, slope phase
I-7	Bodine cherty silt loam
I-9	Bodine cherty silt loam, steep phase
I-10	Bodine cherty silt loam, steep phase
I-13	Mountview silt loam, rolling shallow phase
I-18	Bodine cherty silt loam, slope phase
I-21	Bodine cherty silt loam, slope phase
I-22	Bodine cherty silt loam, slope phase
I-23	Dulac silt loam, eroded rolling phase

TABLE 3. Characteristics of 12 Sycamore Trees Growing on Bottomland Sites on the Western Highland Rim in Tennessee.

Characteristics	Tree Number											
	LI-1	LI-2	LI-3	LI-4	LI-5	LI-6	LI-7	LI-8	LI-9	LI-10	LI-11	LI-12
DBH (inch)	16.6	12.6	14.1	13.4	9.5	13.0	11.7	11.7	12.1	14.3	10.7	9.4
Total height (ft)	76	75	71	62	49	63	73	78	80	60	65	57
Age (years)	25	42	20	15	12	20	19	26	27	30	35	21
Stemform (taper)	good	good	good	good	good	good	good	good	good	good	good	good
Straightness	fair	good	excell.	good	excell.	excell.	good	fair	fair	fair	good	good
Pruning	poor	excell.	poor	fair	fair	fair	excell.	excell.	excell.	fair	fair	excell.
Crown size (ft)	18	15	25	17	16	19	13	11	11	16	12	12
Branches	coarse	med.	coarse	coarse	fine	med.	med.	med.	coarse	med.	med.	fine

sealed with tape. The tubes were immediately put on ice and later placed in a freezer.

The upland trees ranged from 13 years to 31 years of age at breast height (Table 1, page 28), and the bottomland trees ranged from 12 years to 42 years of age at breast height (Table 3). To obtain a balanced design, the first 12 years increments in each core were used for further analysis. Since the proposed breeding program will be for a short rotation of 15 years or less, information on wood properties for the first 12 years of growth will be sufficient.

To analyze the variation in wood properties throughout the first 12 years of growth, the whole cores were divided into six 2-year segments. The cuts were made vertically across the core and parallel with the direction of fibers.

III. Specific Gravity

The specific gravity of wood is determined as grams of dry weight per cubic centimeter of green volume. The green volume of the segments of wood was calculated by measuring each segment to the nearest 0.01 centimeter and using the cylinder formula. Segments were then dried in an oven at 105°C for two days and weighed to the nearest 0.0001 gram. From the green volume and the oven-dry weight, the unextracted specific gravity was calculated.

IV. Extractives

After the unextracted specific gravity was determined, the segments were soaked for 24 hours in distilled water. The segments were then extracted in a Soxhlet apparatus with a 1:2 mixture of alcohol and benzene for 16 hours. Next they were extracted with alcohol for 6 hours. Finally, they were dried for two days in the oven at 105°C and weighed to the nearest 0.0001 gram.

Extractives expressed in g/cc were obtained for each segment by subtracting the specific gravity after extraction from the specific gravity before extraction.

V. Fiber Length

The average fiber length in each two-year segment was estimated by macerating the segment and randomly selecting 50 fibers for measurement. The average of these 50 fibers was taken to be the estimate for the whole segment. Lee (1972) calculated that the average of 50 fibers gave a good estimate of the average fiber length of a 13-17 years core segment of sycamore.

Maceration was conducted by splitting each segment several times in the same direction as the long axis of the fibers. Each segment was placed in a labeled bottle with a solution consisting of one half 10 percent chromic acid and one half 10 percent nitric acid. The wood segments were left for three days in the acid solution. The acid was drained off through a fine mesh screen, and the fibers were rinsed with distilled water.

From each sample bottle, 50 whole fibers were measured. First, two slides were prepared from each bottle using a water mount. To assure a random selection of fibers, the tubes containing the fibers in water were shaken vigorously and the two samples were pipetted from the center

TABLE 4. Analysis of Variance with Expected Mean Squares for Specific Gravity, Fiber Length, and Extractives of Two Populations of Sycamores.

Source of Variation	DF	Expected Mean Squares*
Sites	s-1	$\sigma^2_D + d\ \sigma^2_T + dt\ K^2_S$
Trees in sites	s(t-1)	$\sigma^2_D + d\ \sigma^2_T$
Samples in trees	st(d-1)	σ^2_D
TOTAL	std-1	

* σ^2_D = variance among samples in trees in a site.

σ^2_T = variance among trees in a site.

K^2_S = site effect.

d = number of samples per tree.

t = number of trees per site.

in Table 5; effects are assumed to be random except ring increments which are fixed. Again this model is considered to be mixed.

A third analysis was conducted to determine differences between the sites and among the trees using weighted values for each tree. For specific gravity, fiber length, and extractives, a weighted value was calculated for each increment core within each tree. The data for each two-year segment was weighted by the percentage of the total basal area of the first 12 years of growth of that tree which the two-year segment would represent. The analysis of variance was the same as for the first experiment (Table 4).

The Pearson product-moment correlation coefficients were calculated for all possible pairs of the following variables divided first by site and then by site and two-year segments: unextracted specific gravity, extracted specific gravity, fiber length, extractives, age, and radial growth. The Statistical Analysis System 76 (Barr, Goodnight, Sall, and Helwig, 1976) was used to analyze the data with the PROC CORR procedure.

VII. Rooting Mature Cuttings

Due to the lack of information about variation among sycamore trees in ability to form roots on mature stem cuttings, two experiments were undertaken. The first experiment utilized Hare's treatment (Hare, 1975) on the 12 selected upland sycamores, and the second experiment compared Hare's treatment to several other treatments.

TABLE 5. Analysis of Variance with Expected Mean Squares for the Age Effect in Wood Properties of Sycamores.

Source of Variation	DF	Expected Mean Squares*
Trees	t-1	$\sigma_D^2 + d\ K_R^2 + dr\ \sigma_T^2$
Ring increments/Tree	t(r-1)	$\sigma_D^2 + d\ K_R^2$
Samples/Ring increments	tr(d-1)	σ_D^2
TOTAL	trd-1	

*

σ_D^2 = variance between samples of the same ring increment.

K_R^2 = ring increment (age) effect.

σ_T^2 = variance among trees.

d = number of samples (cores).

r = number of ring increments per core.

t = number of trees.

Experiment 1:

On May 6-8, 1976, branch tips were girdled and the girdle was covered with Hare's paste (1 percent indolebutyric acid; 1 percent 3-methyl-1-phenyl-5-pyrazolone; 20 percent sucrose; 5 percent Captan; 73 percent talc) on each of the 12 trees. Each branch tip (terminals and laterals were both used) was girdled approximately 8 inches from the apical meristem. The girdle was approximately 2 cm wide and did not completely circle the twig; a 1-2 mm bridge of bark, phloem, and cambium was left intact to help the survival of the twig until collection. A paste consisting of Hare's powder in distilled water was then applied completely over the cut surface. This girdle was then wrapped with plastic wrap and aluminum foil and tied in place by a copper wire. On each of the 12 trees, 30 twigs were girdled and treated although only 24 cuttings were needed (8 cuttings for each of three replications); the 6 extra cuttings allowed for some expected mortality. On June 1-2, 1976, the cuttings were taken from the trees and transported to Knoxville in buckets of ice water.

Experiment 2:

On May 20-27, 1976, twigs were girdled on four mature sycamore trees on the Institute of Agriculture campus in Knoxville. Each branch tip (terminal and laterals were both used) was girdled and the paste was applied as in Experiment 1. Ninety twigs were treated on each of four trees allowing four cuttings per experimental unit and eighteen extra cuttings per tree to allow for any mortality taking place before the twigs were harvested. Six treatments consisting of a control and five powders, applied as a paste using distilled water, were used:

TABLE 6. Mean Square Values for Unextracted and Extracted Specific Gravity of Two Populations of Sycamores.

	Source		
	Site (1 DF)	Tree/Site (22 DF)	Samples/Tree (24 DF)
Unextracted Specific Gravity			
0-2 years	0.005594^{NS}	0.002940*	0.001270
3-4 years	0.006129^{NS}	0.002250*	0.000830
5-6 years	0.002919^{NS}	0.002340*	0.000730
7-8 years	0.001174^{NS}	0.001750**	0.000530
9-10 years	0.005515^{NS}	0.002430**	0.000670
11-12 years	0.007844^{NS}	0.001850*	0.000690
Extracted Specific Gravity			
0-2 years	0.002849^{NS}	0.002640*	0.001240
3-4 years	0.004100^{NS}	0.001900*	0.000730
5-6 years	0.001181^{NS}	0.001980**	0.000720
7-8 years	0.000830^{NS}	0.001620*	0.000600
9-10 years	0.003343^{NS}	0.002150**	0.000560
11-12 years	0.007905*	0.001590**	0.000570

*Significant at the 5 percent probability level.

**Significant at the 1 percent probability level.

^{NS}Not significant at 5 percent probability level.

TABLE 7. Mean Square Values and Variance Components in Percent for Weighted Unextracted Specific Gravity of Two Populations of Sycamores.

Source	DF	MS	Variance Component	Percent of Total Variation
Sites	1	0.005600^{NS}	K_S^2	16
Trees/Site	22	0.001482**	σ_T^2	51
Samples/Tree	24	0.000367	σ_D^2	33
TOTAL	47			100

**Significant at the 1 percent probability level.

^{NS}Not significant at the 5 percent probability level.

TABLE 8. Variance Components in Percent for Unextracted and Extracted Specific Gravity of Two Populations of Sycamores.

Variance Component	0-2 years	3-4 years	5-6 years	7-8 years	9-10 years	11-12 years
<u>Unextracted Specific Gravity</u>						
K_S^2	5	9	1	0	8	17
σ_T^2	38	42	52	54	52	38
σ_C^2	57	49	47	46	40	45
TOTAL	100	100	100	100	100	100
<u>Extracted Specific Gravity</u>						
K_S^2	1	7	0	0	4	20
σ_T^2	36	41	47	46	56	38
σ_C^2	63	52	53	54	40	42
TOTAL	100	100	100	100	100	100

TABLE 9. Mean Square Values and Variance Components in Percent for Specific Gravity, Extractives, and Fiber Length for the Upland Population of Sycamores.

Source	DF	MS	Variance Component	Percent of Total Variation
Unextracted Specific Gravity				
Tree	11	0.00486**	σ_T^2	17
Ring increment/Tree	60	0.00161*	K_R^2	21
Samples/Ring increment	72	0.00097	σ_D^2	62
TOTAL	143			100
Extracted Specific Gravity				
Tree	11	0.00459*	σ_T^2	17
Ring increment/Tree	60	0.00153*	K_R^2	22
Samples/Ring increment	72	0.00089	σ_D^2	61
TOTAL	143			100
Extractives				
Tree	11	0.000169**	σ_T^2	37
Ring increment/Tree	60	0.000021^{NS}	K_R^2	1
Samples/Ring increment	72	0.000020	σ_D^2	62
TOTAL	143			100
Fiber Length				
Tree	11	0.07082^{NS}	σ_T^2	8
Ring increment/Tree	60	0.04376**	K_R^2	68
Samples/Ring increment	72	0.00655	σ_D^2	24
Total	143			100

*Significant at the 5 percent probability level.

**Significant at the 1 percent probability level.

^{NS}Not significant at the 5 percent probability level.

TABLE 10. Mean Square Values and Variance Components in Percent for Specific Gravity, Extractives, and Fiber Length for the Bottomland Population of Sycamores.

Source	DF	MS	Variance Component	Percent of Total Variation
Unextracted Specific Gravity				
Tree	11	0.01282**	σ_T^2	51
Ring increment/Tree	60	0.00129**	K_R^2	18
Samples/Ring increment	72	0.00060	σ_D^2	31
TOTAL	143			100
Extracted Specific Gravity				
Tree	11	0.01050**	σ_T^2	49
Ring increment/Tree	60	0.00107*	K_R^2	15
Samples/Ring increment	72	0.00059	σ_D^2	36
TOTAL	143			100
Extractives				
Tree	11	0.000173**	σ_T^2	27
Ring increment/Tree	60	0.000039*	K_R^2	20
Samples/Ring increment	72	0.000022	σ_D^2	53
TOTAL	143			100
Fiber Length				
Tree	11	0.10323**	σ_T^2	28
Ring increment/Tree	60	0.2738**	K_R^2	48
Samples/Ring increment	72	0.00559	σ_D^2	24
TOTAL	143			100

*Significant at the 5 percent probability level.

**Significant at the 1 percent probability level.

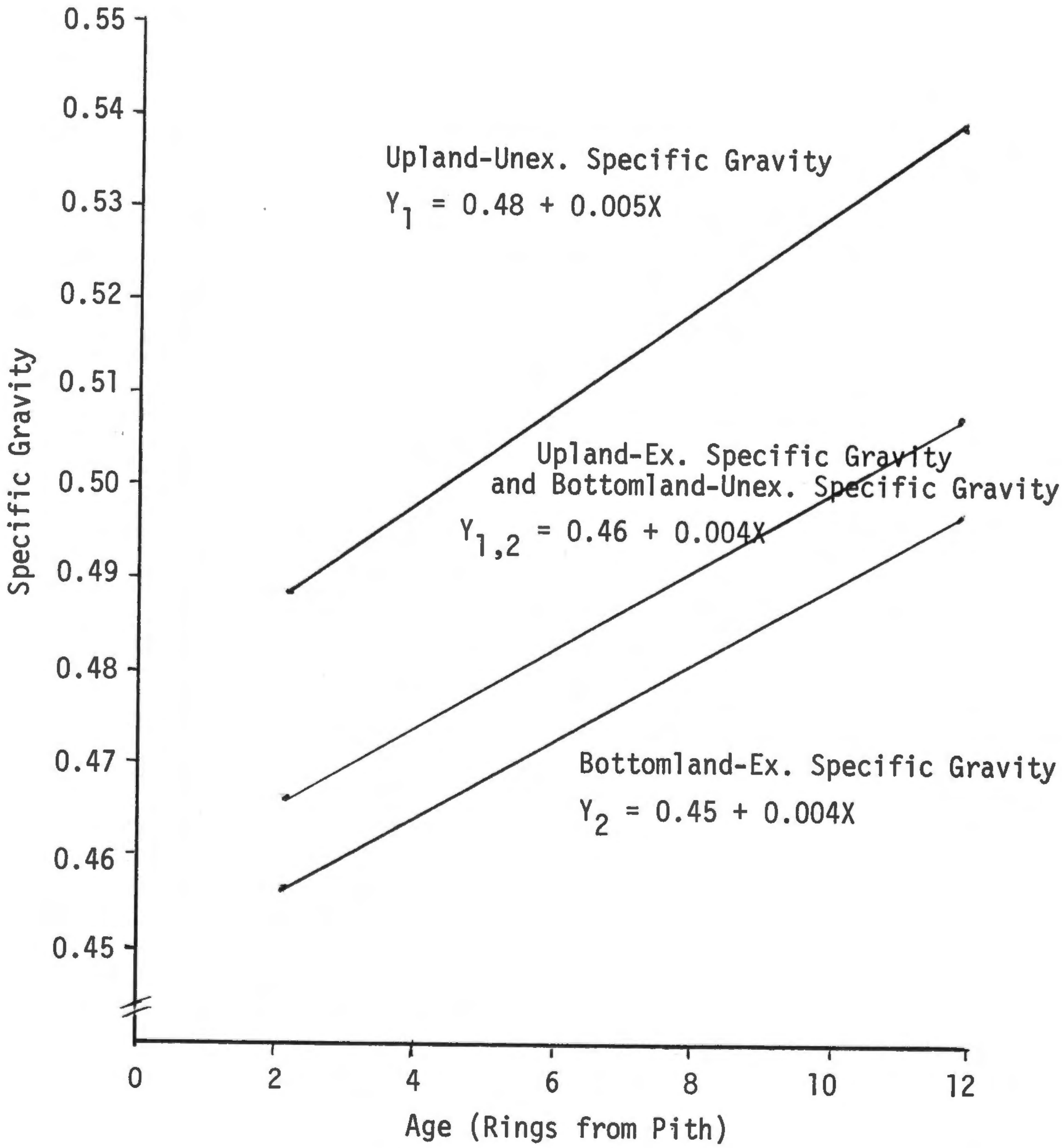

FIGURE 3. Relationship of Age (X) with Unextracted (Y_1) and Extracted (Y_2) Specific Gravity of Upland and Bottomland Sycamore Trees.

TABLE 11. Mean Square Values for Extractives and Fiber Lengths of Two Populations of Sycamores.

	Source		
	Site (1 DF)	Tree/Site (22 DF)	Cores/Tree (24 DF)
Extractives			
0-2 years	0.000549**	0.000051**	0.000014
3-4 years	0.000203*	0.000053**	0.000019
5-6 years	0.000387**	0.000044*	0.000020
7-8 years	0.000053^{NS}	0.000041^{NS}	0.000021
9-10 years	0.000270*	0.000051^{NS}	0.000030
11-12 years	0.000000^{NS}	0.000046^{NS}	0.000024
Fiber Length			
0-2 years	0.369480**	0.035530**	0.012230
3-4 years	0.30755**	0.02644**	0.00574
5-6 years	0.16366**	0.01912**	0.00499
7-8 years	0.170670**	0.012410**	0.003100
9-10 years	0.125860*	0.019340**	0.005250
11-12 years	0.104940*	-.012410**	0.005090

*Significant at the 5 percent probability level.

**Significant at the 1 percent probability level.

^{NS}Not significant at the 5 percent probability level.

TABLE 12. Variance Components in Percent for Extractives and Fiber Lengths of Two Populations of Sycamores.

Variance Component	0-2 years	3-4 years	5-6 years	7-8 years	9-10 years	11-12 years
Extractives						
K_S^2	34	15	31	1	18	0
σ_T^2	38	40	26	33	22	31
σ_c^2	28	45	43	66	60	69
TOTAL	100	100	100	100	100	100
Fiber Length						
K_S^2	37	42	33	46	27	21
σ_T^2	31	37	39	32	42	49
σ_c^2	32	21	28	22	31	30
TOTAL	100	100	100	100	100	100

TABLE 13. Mean Square Values and Variance Components in Percent for Weighted Total Extractives of Two Populations of Sycamores.

Source	DF	MS	Variance Component	Percent of Total Variation
Sites	1	0.000100^NS	K_S^2	14
Trees/Site	22	0.000027**	σ_T^2	48
Samples/Tree	24	0.000008	σ_D^2	38
TOTAL	47			100

**Significant at the 1 percent probability level.

NS Not significant at the 5 percent probability level.

six years; but then the difference becomes nonsignificant for the next six years (Table 11). The amount of the total variation due to the trees-within-site source of variation is fairly consistent and is approximately 31 percent (Table 12). When the segments are taken together in the weighted extractive values, a highly significant difference is apparent among trees within the same site (Table 13). This source of variation accounts for 48 percent of the total variation. Therefore, it may be possible to make gains in reducing the total amount of extractives by selecting trees which have lower amounts of extractives.

Because of the design of the first experiment (Table 11), the significance of the difference between the two samples (one from each increment core) of each two-year wood segment cannot be determined; but the contribution of this source to the total variation is determined to be approximately 52 percent (Table 12).

This source of variation is consistently the largest of the three sources and can be seen to increase from 28 percent of the total variation in the zero to two years segment to the 69 percent of the total variation in the eleven to twelve years segment. This fact may indicate that physiological variation within the tree is relatively small at first allowing differences among trees to become statistically significant; but with increasing rings from the pith, the amount of variation due to physiological differences within the trees becomes larger and larger until it finally overshadows any differences in extractives among the different trees.

In the analysis of variance with weighted extractives, the amount of variation due to the samples-within-tree source accounts for 38 percent of the total variation in extractives.

Another analysis of variance (Tables 9 and 10, pages 47 and 48, respectively), was conducted to determine the variation among the six two-year wood segments within each tree. Differences among the six wood segments within each tree were significant for the bottomland trees but nonsignificant for the upland trees. These differences accounted for less than 1 percent of the total variation within upland trees and 20 percent of the total variation in bottomland trees. Differences in extractives between the two samples (One from each increment core) accounted for 62 and 53 percent of the total variation for the upland and bottomland trees, respectively.

The difference in extractives appears to be controlled to some extent by genetics of the individual trees for the first six years as indicated by the significant difference among trees within each site. For the next six years as the trees are getting larger, environment x genetic interaction may result in greater physiological differences within each tree. This variation increases each year from the pith outward; from the seven to eight growth rings till the 11-12 year segment, this variation is so large that it negates any significance of the among-tree variation.

Fiber Length

An analysis of variance was conducted for each of the six two-year wood segments separately (Table 11, page 51) and also for weighted fiber length (Table 14) which compares different sites and trees using a single value for the first 12 years of growth at breast height.

TABLE 14. Mean Square Values and Variance Components in Percent for Weighted Fiber Length of Two Populations of Sycamores.

Source	DF	MS	Variance Component	Percent of Total Variation
Sites	1	0.1174**	K_S^2	42
Trees/Site	22	0.0116**	σ_T^2	55
Samples/Tree	24	0.0003	σ_D^2	3
TOTAL	47			100

**Significant at the 1 percent probability level.

The difference between the two sites is significant for four of the six segments with this source accounting for approximately 34 percent of the total variation (Table 12, page 52). For the weighted fiber lengths, the difference between the sites is also significant and accounts for 42 percent of the total variation. Reports in the literature for other diffuse-porous hardwood species seem to be contradictory concerning this source of fiber length variation. With sweetgum, Webb (1964) found no significant difference in fiber length between the upland and bottomland sites. However, in a cottonwood study, Wilcox and Farmer (1968) found a significant difference in fiber length among transects. In this sycamore study, the bottomland trees had longer fiber lengths than the upland trees. Environmental effects may play a major role due to the fact that a droughty situation may prevail during the summer on the upland sites causing the fibers in the summerwood portion of the growth ring to be relatively shorter. A progeny test is needed to determine whether this difference in fiber length is environmental or genetic.

Fiber length is also significantly different among the trees within each site for each segment (Table 11, page 51). This source of variation accounts for 38 percent of the total variation (Table 12, page 52) with the amount of variation accounted for by this source apparently increasing from 32 percent for the first two-year segment to 49 percent for the 11-12 year segment. An increasing amount of the total variation from the pith outward accounted for by trees has also been reported for yellow-poplar (Thorbjornsen, 1961). This finding may indicate that environmental factors play a heavier role in determining fiber length of younger trees; and as the trees increase in age, the genetic differences among trees begin to account for more and more of the variation in fiber lengths.

With weighted fiber length values, the difference in fiber length among trees within a site is significant and accounts for 55 percent of the total variation (Table 14, page 56). Taylor (1969), Schmitt and Wilcox (1969), and Lee (1972) in their sycamore work also found significant differences at this level of variation.

The significance of the variation between fiber lengths of the two samples (one from each increment core) of each wood segment could not be tested. However, the amount of the total variation due to this source of variation is approximately 27 percent (Table 12, page 52). For the weighted fiber lengths, the between-sample source of variation is very small, accounting for only 3 percent of the total variation. Apparently the weighting process reduces the between-sample variation by a great amount for fiber length.

Variation in fiber length among the six two-year wood segments within each tree could be tested and was found to be significant for both upland and bottomland trees (Tables 9 and 10, pages 47 and 48, respectively). A significant difference is present among the trees on the bottomland site but not on the upland site. This finding may appear to be in conflict with the results of Table 11, page 51), but the significant differences shown for the trees-within-site source of variation in Table 11 were obtained for bottomland and upland trees combined. Also, the variation among the six two-year wood segments did not enter into the analysis in Table 11 because a separate analysis was conducted for each wood segment. The amount of variation due to the ring increment-within-tree source of variation is so great that it accounts for approximately 58 percent of the total variation; this source, when included in an analysis, overshadows the other sources of variation.

Correlations and Regressions

The relationship between age and radial growth is significant for both the upland and bottomland populations with correlation coefficients of -0.23 and -0.43, respectively (Table 15). Although the growth rings of the trees decrease in width, as age increases from the pith, the basal area represented by the growth ring generally increases in successive rings from the pith.

Extracted specific gravity increases significantly with increasing rings from the pith. For the upland and bottomland populations, the correlation coefficients are 0.40 and 0.33, respectively (Table 15). This finding is in agreement with the results of Taylor (1969), Schmitt and Wilcox (1969), and Lee (1972) who also found an increase in specific gravity with successive rings from the pith.

When unextracted and extracted specific gravity are regressed on age of the segment (Figure 3, page 50), regression equations are calculated which account for 16 percent of the total variation in specific gravity for the upland population and 13 percent and 11 percent of the total variation in the bottomland population for unextracted and extracted specific gravity, respectively. This graph indicates that specific gravity is somewhat higher in the upland population; but the difference is nonsignificant for a weighted value and for each segment taken separately, except for the 10-12 year segment.

TABLE 15. Significant* Correlations Among Breast Height Age, Growth Rate, and Wood Properties for Upland and Bottomland Sycamore Trees.

Relationship	Correlation Coefficients Upland	Correlation Coefficients Bottomland
age x radial growth	-0.23	-0.43
age x extracted specific gravity	0.40	0.33
age x extractives	NS	0.33
age x fiber length	0.71	0.59
radial growth x extracted specific gravity	0.29	NS
unex. specific gravity x ex. specific gravity	0.99	0.99
ex. specific gravity x extractives	0.17	0.46
ex. specific gravity x fiber length	0.43	0.27
extractives x fiber length	NS	0.26

*All correlations significant at 1 percent probability level.

[NS]Not significant at 5 percent probability level.

NOTE: n = 144.

Extractive content is observed to increase (r = 0.33) significantly with age from the pith for the bottomland population, but the relationship was nonsignificant for the upland sycamore population. Thorbjornsen (1961) in his yellow-poplar study also found no increase in total extractives with age from the pith.

When extractives was regressed on age of the segment for the upland population and the square of age for the bottomland population, the regression equations accounted for 1 percent and 13 percent, respectively of the total variation in extractives (Figure 4). A test of the homogeneity of the two regression coefficients resulted in no significant difference at the 5 percent probability level which indicates that the slopes of the two regression lines are not different.

To check the effect of the different total ages of the selected trees on the extractives present, a correlation was calculated between the total age at breast height and the average amount of extractives of the first 12 years for each tree. This correlation coefficient was -0.52 and was significant at the 1 percent probability level. However, when correlation coefficients were calculated for the two populations separately, neither correlation coefficient (r = -0.38 and r = -0.45) was significant with only 10 degrees of freedom. Since both correlation coefficients were negative, there is no indication that extractable material had been deposited in heartwood formation.

Fiber length is found to be significantly correlated with age, and the correlation coefficient is 0.71 for the upland population and 0.59 for the bottomland population. The regression equations (Figure 5) account for 50 percent of the variation in the fiber length in the

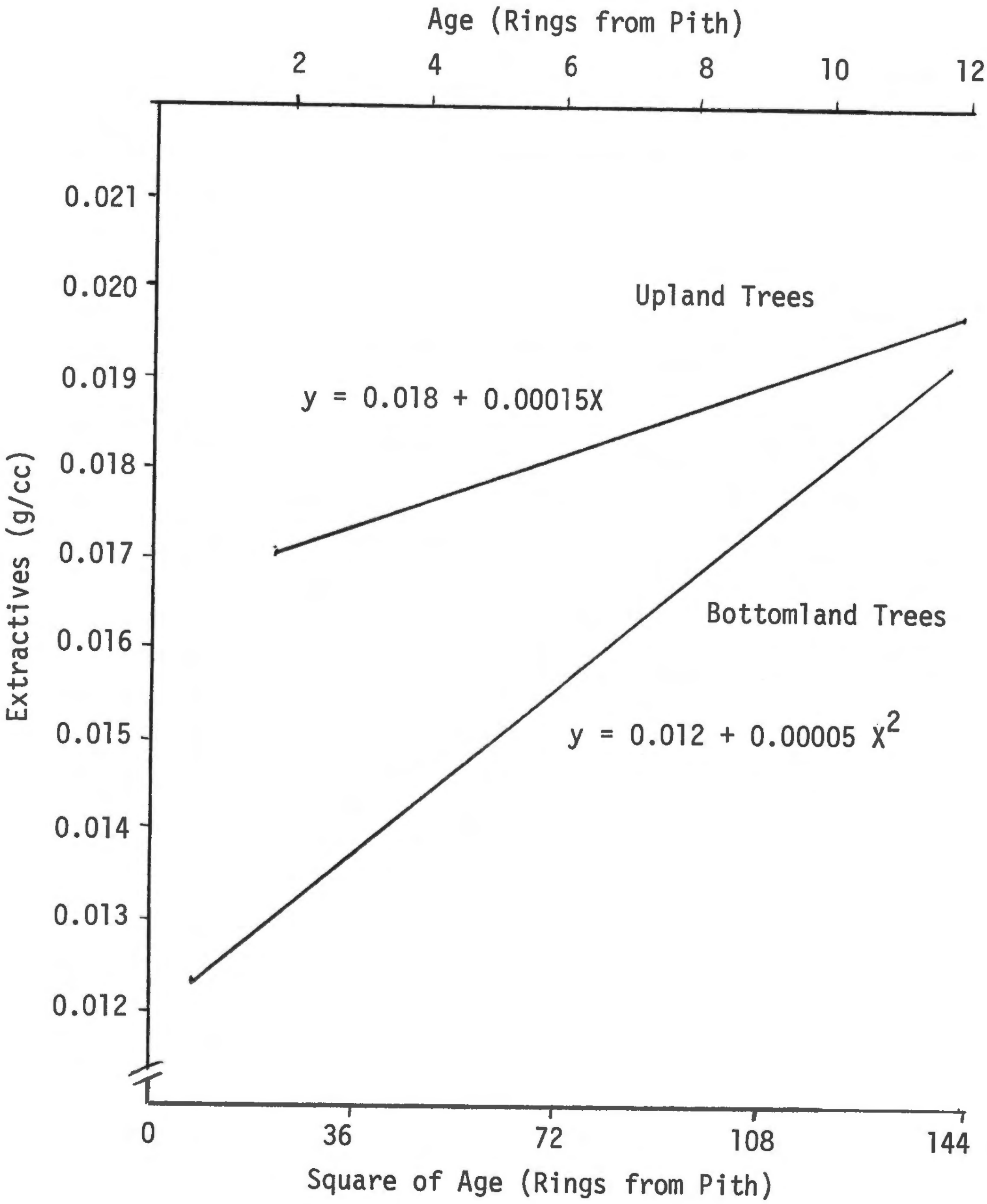

FIGURE 4. Relationship of Age with Extractives of Upland and Bottomland Sycamore Trees.

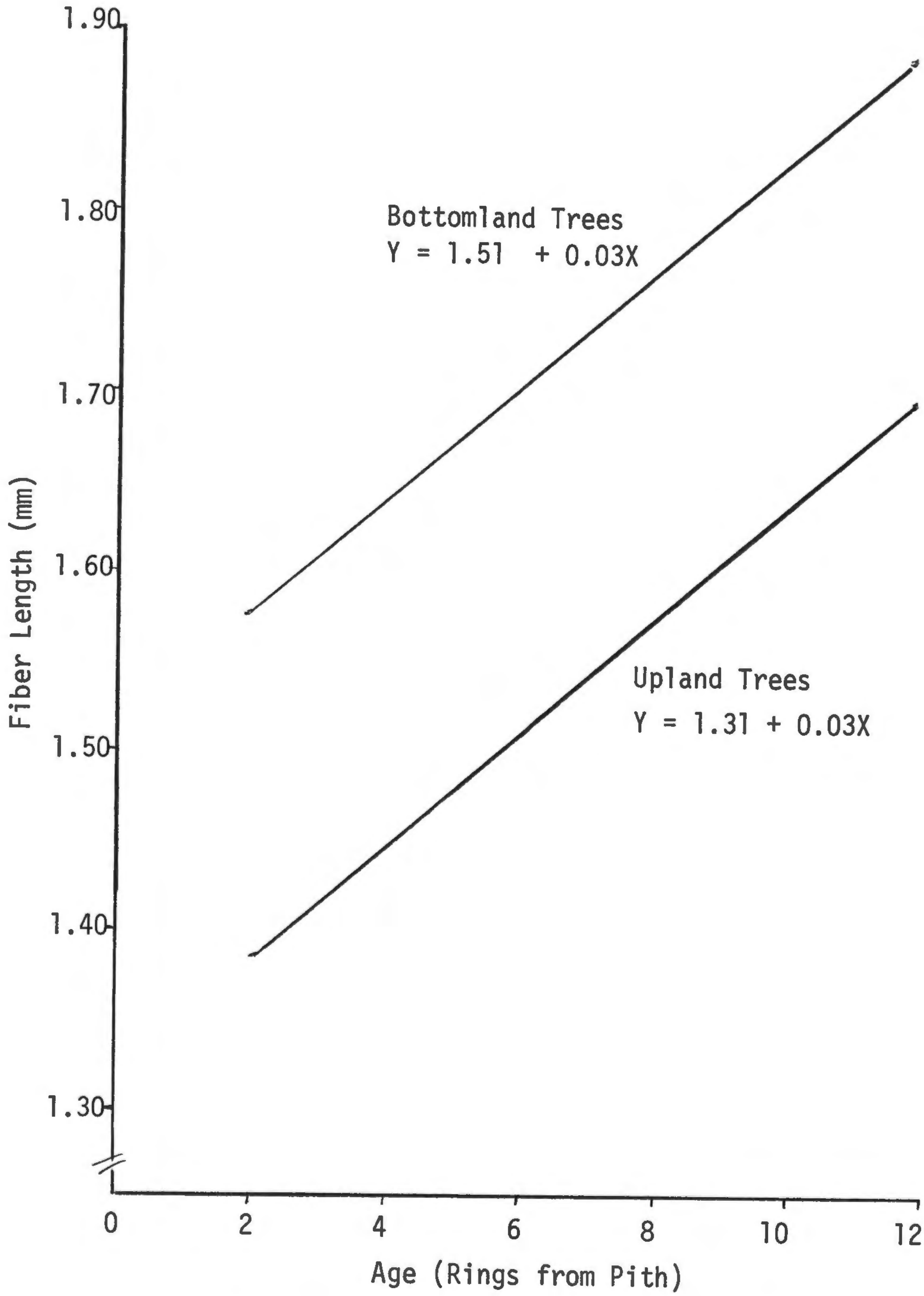

FIGURE 5. Relationship of Age with Fiber Length of Upland and Bottomland Sycamore Trees.

upland population and 35 percent of the variation in fiber length in the bottomland population. This increase in fiber length with age agrees with the findings of Schmitt and Wilcox (1969), Taylor (1969), McElwee, Tobias, and Gregory (1970), and Lee (1972). With successive rings from the pith, the cambial initials go first through a juvenile stage and finally into maturity. During this process, the fibers which are formed are longer in each successive ring until a leveling off occurs at approximately 15 to 20 years of age.

Radial growth is significantly correlated with extracted specific gravity for the upland population with a correlation coefficient of 0.29. The bottomland population, however, has no significant correlation between radial growth and extracted specific gravity. The results for the upland population agree with observations made by Saucier and Ike (1969b). This finding presents the possibility that faster growth of trees may also improve the specific gravity of the wood produced.

Unextracted specific gravity is significantly correlated with extracted specific gravity with a correlation coefficient of 0.99 for both of the populations. This result is to be expected since the difference between extracted and unextracted specific gravity is due to relatively small amounts of extractives (Figure 3, page 50).

Since extracted specific gravity, extractives, and fiber length are significantly and positively correlated with age, their positive correlation with each other is anticipated. When the correlation coefficients are calculated for individual two-year segments separately (removing effect of age), the correlations between any two of these variables (extracted specific gravity, extractives, and fiber length) become nonsignificant. This result agrees with the findings of Schmitt and Wilcox (1969) and Lee (1972) who analyzed only single increment segments from each increment core and therefore avoided any significant correlations due to a mutual relationship with age.

In the upland population, growth rate and fiber length are significantly and positively correlated for the first two wood segments; whereas in the bottomland population, this relationship is significant only in the first wood segment (Table 16).

When correlations are conducted on the two-year segments (which removes age and any correlations strictly due to its influence), extracted specific gravity in the upland population is still significantly and positively correlated with radial growth (Table 16). The correlation coefficients are higher at the individual segment level than when the segments were all combined probably by removal of the negative relationship between radial growth and age. This information further substantiates the probability of achieving gains in specific gravity by increasing growth rate of the upland population of trees.

II. Rooting of Mature Hardwood Cuttings

Because of the high number of non-rooted cuttings and therefore zero values, the frequency distributions were highly skewed to the low end of the scale. All attempts to aid the normality of the frequency distributions failed and consequently non-parametric tests were used to analyze the data.

TABLE 16. Significant* Correlations Among Growth Rate, Fiber Length, and Extracted Specific Gravity by Two-Year Core Segment for Upland and Bottomland Sycamore Trees.

Relationship	Correlation Coefficient	
	Upland	Bottomland
0-2 years--growth rate x fiber length	0.50	0.52
3-4 years--growth rate x fiber length	0.42	NS
3-4 years--extracted sp. gr. x growth rate	0.46	NS
5-6 years--extracted sp. gr. x growth rate	0.42	NS
7-8 years--extracted sp. gr. x growth rate	0.72	NS
11-12 years--extracted sp. gr. x growth rate	0.42	NS

*All correlations significant at 5 percent probability level.

NS Not significant at 5 percent probability level.

NOTE: n = 24.

Among-Tree Variation

Results from a Chi-square test using the 12 upland trees indicate that there is a significant relationship (at the 1 percent probability level) between individual trees and percentage of rooted cuttings. With 11 degrees of freedom, the Chi-square value was 36.58. The range in rooting response among the 12 trees was quite large with the poorest tree producing 8 percent rooted cuttings and the best tree producing 83 percent rooted cuttings (Table 17).

In the experiment designed to test six different rooting treatments, the four different trees used were also analyzed for a relationship between tree and percentage of rooted cuttings. To do this, the six treatment totals were pooled within each tree. A Chi-square test indicated a significant relationship (at the 1 percent probability level) between tree and number of rooted cuttings. With 3 degrees of freedom, the Chi-square value was 22.16. The rooting response for the four trees was 17, 29, 44, and 63 percent, respectively.

Results of these Chi-square tests support the findings of Snow (1939) and indicate that genotypes of sycamores differ in rooting ability. Also, this experiment points to the ability of mature sycamore trees to produce stem cuttings which are able to root. This part of the results is in agreement with Hare (1975), but the percentage of rooted cuttings is somewhat lower; and whereas all of Hare's cuttings rooted, the cuttings in these two experiments showed strong among-tree variation in ability to root.

To obtain an estimate of the quality of the root mass produced on rooted cuttings, the number of main roots and the length of the longest

TABLE 17. Number of Rooted Cuttings per Tree Obtained from the 12 Selected Upland Sycamore Trees and Chi-square Test.

Tree Number	Number of Rooted Cuttings (24 attempted)	Percent of Cuttings Which Rooted
I-18	20	83
I-23	14	58
I-5	14	58
I-3	13	54
I-1	12	50
I-2	12	50
I-9	11	46
I-21	8	33
I-7	5	21
I-22	3	13
I-10	2	8
I-13	2	8

NOTE: DF = 11; X^2 = 36.58**.

**Significant at the 1 percent probability level.

main root were recorded for each cutting (mean values are in Table A-4). The results of a Kruskal-Wallis One-Way Analysis of Variance test revealed that the 12 upland trees are significantly different (1 percent probability level) in their number of main roots per rooted cutting. Furthermore, the results of the same test for length of the longest main root per rooted cutting indicate that the 12 upland trees are significantly different (1 percent probability level).

Pearson product-moment correlation coefficients were calculated for the following combinations of three variables: number of main roots per cutting x length of longest main root per cutting, number of rooted cuttings per tree x average number of main roots per cutting, and number of rooted cuttings per tree x average length of the longest main root per cutting. The correlation coefficients were 0.82, 0.85, and 0.85, respectively; all correlation coefficients were significant at the 1 percent probability level. Although a cause and effect relationship can not be drawn from Pearson product-moment correlation coefficients, it can be said that all three of these variables increase positively together. Therefore, it appears that the cuttings from trees which have a better rooting ability also have more main roots and longer roots.

Hormone Treatments

To this date, only one technique has been presented in the literature (Hare, 1975) for rooting mature stem cuttings of sycamore. An experiment which compared this technique with a check and four other chemical treatments on four selected mature sycamores (mean values are in Table A-5) revealed that while the reported technique gave some rooted cuttings, the check and the other four treatments produced a larger percentage of rooted cuttings. A Chi-square test revealed a significant relationship (at the 5 percent probability level) between the hormone treatment and number of rooted cuttings (Table 18).

It appears that partial girdling of the stem, covering the girdle, and leaving it on the tree for a month before collection provides some rooting of the mature cuttings. Only two of the hormone treatments exceeded the check treatment in the number of rooted cuttings which they produced. These two treatments utilized 1 percent IAA and 0.8 percent IBA and produced 63 percent and 44 percent rooted cuttings, respectively. Ethrel, 3-methyl-1-phenyl-5-pyrazolone, sucrose, and Captan in various combinations seemed to inhibit rooting of the stem cuttings.

As a further attempt to check the quality of the rooted cuttings, a Friedman Two-Way Analysis of Variance test was conducted on both the number of main roots per cutting and the length of the longest main root per cutting. Using this test, no significant evidence was found that the different hormone treatments had any differential effect on number of main roots per cutting or on the length of the longest main root per cutting. Mean values for number of main roots per cutting and length of longest main root per cutting are presented in Tables A-6 and A-7, respectively; only cuttings which had rooted were included in calculating the means.

One major problem encountered with all trees and all treatments was leaf drop during the period cuttings were in the mist bench. Cuttings from some trees tended to drop more of their leaves, but all of the trees had some leaf drop on their cuttings. In several instances a

TABLE 18. Effect of Hormone Treatments on Rooting of Cuttings from Four Sycamore Trees and Chi-square Test.

Hormone Treatment	Number of Rooted Cuttings (48 attempted)	Percent of Cuttings Which Rooted
1 percent IAA	30	63
0.8 percent IBA	21	44
check	20	42
Hare's tmt. + 10 ppm ethrel	16	33
0.8 percent IBA + 10 ppm ethrel	13	27
Hare's tmt.	10	21

NOTE: DF = 5; X^2 = 13.62*.

*Significant at 5 percent probability level.

cutting would root while the leaves were still alive; but when the leaves dropped, the cutting died within one or two months.

A number of variables may affect the rooting of cuttings of any type of plant. The rooting environment must be precisely fixed and kept constant in order to determine the results from different treatments. Little is known about the effect of plant hormones on rooting, and therefore this rooting process is still a hit or miss proposition. The rooting ability of cuttings from different individuals within a species may vary widely, and this variation must be taken into account when developing new rooting techniques for that species. Within a given genotype there is also much variation in rooting response, particularly when comparing juvenile and mature tissue. The genotype x environment interaction is also an important consideration, especially in hard-to-root species or varieties; a given genotype may have different phenotypic expressions (such as rooting ability) when exposed to various treatments.

III. Ranking System

The best method for selecting superior mother trees is to conduct progeny tests on several sites similar to those on which the trees will be grown. This method will also allow genetic, environmental, and genotype x environment interaction variance components to be estimated for the characteristics being studied.

However, since the company may not want to wait for the results of progeny tests, the next best selection system entails rating the trees in the original population for important commercial characteristics; the rating for each characteristic is then weighted as to its economic importance and summed to produce a total which may be used to rank the selected trees. The procedure used is modeled after a technique used by Farmer (1973). The 12 upland trees are ranked with 1 being the best tree and 12 being the poorest tree. This phenotype selection approach is far from perfect, but since the upland trees are growing on similar sites this method will at least give some idea as to the relative value of the trees in a breeding program.

The diameter at breast height for the first 12 years growth, weighted extracted specific gravity, weighted fiber length, and weighted total extractives are presented in Table 19. These four characteristics plus the ratio of crown radius to diameter breast height, stemform, straightness, pruning, branch diameter, and rooting percent are all incorporated in the ranking system so that the tree with the highest score is ranked 1 and the lowest score is 12.

Ten characteristics were considered to be important in this selection system (Table 20). The characteristics are listed with their respective criterion weight in parentheses: 1) Crown radius (ft)/DBH (inch)--this characteristic was chosen because the most efficient trees have a relatively small crown in relation to their diameter. It was assigned a small criterion weight (1) because most of these trees were open grown which led to larger than average crowns. 2) DBH of the first 12 years growth is a reflection of growth rate and is considered to be very important (5). 3) Stemform----tree taper is usually considered to be important with the best trees having least taper (2). 4) Straightness--one of the major objectives of any breeding program is to grow trees as straight as possible (2). 5) Pruning--since the bole

TABLE 19. Diameter at Breast Height for First 12 Years, Weighted Extracted Specific Gravity, Weighted Fiber Length, and Weighted Extractive Content for the Upland Sycamore Population.

Tree	DBH (12 years) (cm)	DBH (12 years) (inch)	Weighted Extracted Specific Gravity	Weighted Fiber Length (mm)	Weighted Extractives (g/cc)
I-1	13.3	5.44	0.492	1.74	0.0146
I-2	14.5	5.94	0.497	1.57	0.0190
I-3	11.9	4.86	0.494	1.55	0.0223
I-5	19.7	8.02	0.495	1.51	0.0165
I-7	12.1	4.96	0.491	1.65	0.0175
I-9	18.4	7.50	0.491	1.63	0.0179
I-10	14.1	5.76	0.477	1.62	0.0182
I-13	8.53	3.48	0.491	1.65	0.0176
I-18	32.7	13.34	0.555	1.65	0.0228
I-21	17.8	7.28	0.505	1.54	0.0303
I-22	14.0	5.70	0.528	1.64	0.0176
I-23	19.8	8.08	0.522	1.72	0.0155
Mean	16.4	6.70	0.503	1.62	0.0191
s^2	38.07	6.32	0.0005	0.0049	0.000018
s	6.17	2.51	0.021	0.07	0.0042

TABLE 20. Selection Index for the Upland Population of Sycamores.

Characteristic No.	1	2	3	4	5	6	7	8	9	10	Score	Rank
Criterion Weight	(1)	(5)	(2)	(2)	(1)	(2)	(6)	(5)	(3)	(3)		
I-1	+*	0	0	0	0	-	0	+	+	+	10	1
I-22	+	0	+	+	+	0	+	0	0	-	9	2
I-18	0	+	-	-	-	-	+	0	0	+	7	3
I-23	0	0	0	0	0	-	0	+	0	+	6	5
I-3	0	0	0	0	0	+	0	0	0	+	5	5.5
I-7	0	0	+	+	++	+	0	0	0	-	5	5.5
I-2	0	0	0	0	-	+	0	0	0	+	4	7
I-9	0	0	+	0	+	0	0	0	0	-	0	8
I-5	0	0	-	0	-	0	0	-	0	+	-5	9.5
I-10	-	0	+	+	+	0	-	0	0	-	-5	9.5
I-13	0	-	0	-	0	0	0	0	0	-	-10	11.5
I-21	0	0	0	0	-	+	0	-	-	-	-10	11.5

*Rating values: "+" = +1; "-" = -1; "0" = 0.

wood is the desirable source of fiber for pulp, minimizing the length of the crown to about 1/3 of the total height is important in reducing the number of limbs. Many of the trees were open grown, therefore, this characteristic was assigned a low criterion weight (1). 6) Branch diameter--larger branches usually slow down harvesting operations and also increase the total percentage of the less desirable fiber which comes from branch wood (2). 7) Extracted specific gravity--extracted specific gravity has been shown to be a heritable characteristic which can be improved through breeding programs; it is of great economic importance to pulp and paper industries (6). 8) Fiber length--although fiber length is often disregarded in breeding programs because of narrow phenotypic variation and low percentage of variation due to among-stands or among-tree source of variation, the results of this study show a relatively good phenotypic variation and a large percentage of variation due to the among-tree source (5). 9) Extractives--the low amount of extractives in young sycamores reduces the importance of this characteristic in a breeding program, but significant variation does exist in the first three two-year segments among-trees within a site (3). 10) Rooting--although this characteristic has no importance in the pulping process, it opens opportunities in relation to development of clonal lines of sycamore (3).

Table 20 presents the rating, scoring, and ranking of the 12 upland trees. For characteristics 1, 2, 7, 8, and 9, frequency distributions were developed and trees falling within one standard deviation of the mean received a rating of "zero." Trees which fell below one standard deviation from the mean for characteristics 1 and 9 received a rating of "+" because decreasing these characteristics would represent an improvement; the same reasoning warrants a "-" for trees which fell above one standard deviation from the mean. For characteristics 2, 7, and 8, trees which fell below one standard deviation from the mean received a "-"; if they fell above one standard deviation from the mean, they received a "+." For characteristic number 10, a tree which had 50 percent or better rooting received a "+," and a tree which had less than 50 percent rooting received a "-." The following characteristics received the ratings given in parentheses: 3) good (+), fair (0), poor (-); 4) excellent (+), good (0), fair (-); 5) excellent (++), good (+), fair (0), poor (-); 6) coarse (-), medium (0), fine (+).

From this ranking system, it is easy to see that some of the trees are phenotypically superior to others. However, one major limitation with this program is the size of the population. In order to establish a viable breeding program, at least 30 superior trees should be selected out of a larger population. This breeding population size is a minimum to retain sufficient genetic variability for future selection. A more variable population will also give some assurance that plantations will not be destroyed by insects or disease.

CHAPTER V

SUMMARY

The objective of the study was to evaluate natural variation in specific gravity, fiber length, total extractives, and rooting ability of mature stem cuttings of American sycamore (*Platanus occidentalis* L.) growing on upland sites on the western Highland Rim in Middle Tennessee. Twelve upland trees were selected which had a minimum age of 12 years at breast height; for comparison purposes, an equal number of bottomland trees were selected which were also at least 12 years old at breast height. The upland trees were all located on disturbed sites with acid to highly acid soils.

Using weighted values for each tree, no significant difference occurred for unextracted specific gravity and extractives between the upland and bottomland sites. For fiber length, however, there was a significant difference between the two sites with the bottomland trees having longer fibers.

When the first 12 years growth from the pith was divided into six two-year segments, the between-site difference was found to be significant for all six wood segments for fiber length with this source accounting for about 34 percent of the total variation. Four of the six segments indicated between-site differences in extractives. This source of variation was nonsignificant for all six wood segments for both unextracted and extracted specific gravity except for the 11-12 year segment for extracted specific gravity which was significant. Extractives in the upland population averaged 3.7 percent of the mean unextracted specific gravity of all the segments combined; in the bottomland population, extractives averaged 3.1 percent of the mean unextracted specific gravity of all the segments combined. Weighted values of unextracted specific gravity, fiber length, and extractives showed a significant difference among trees within the same site. This source of variation accounts for 51, 55, and 48 percent of the total variation in weighted unextracted specific gravity, weighted fiber length, and weighted extractives, respectively.

Among-tree differences were significant for unextracted and extracted specific gravity and fiber length for all six two-year wood segments and for the first three two-year segments for wood extractives. This source of variation accounted for about 50 percent of the total variation for unextracted and extracted specific gravity, 38 percent of total variation in fiber length, and 31 percent of the total variation in the first three two-year segments for extractives. The mean for unextracted specific gravity was 0.514 for the upland trees with a range of 0.367 to 0.615 and a mean of 0.495 for the bottomland trees with a range of 0.394 to 0.613. For fiber length, the mean was 1.56 mm for the upland trees with a range of 1.13 mm to 1.90 mm and a mean of 1.69 mm for the bottomland trees with a range of 1.26 mm to 2.10 mm.

Significant positive relationships exist between age of segment and extracted specific gravity ($r = 0.40$ for upland population and $r = 0.33$ for bottomland population) and between age of segment and fiber length ($r = 0.71$ for upland population and $r = 0.59$ for bottomland population). Extractives increase significantly and positively with age of the segment for the bottomland population. Extracted specific gravity increases significantly with radial growth (r = 0.29) in the upland population with all segments combined. When the segments are analyzed separately removing age effect, the correlation coefficients for the relationship between extracted specific gravity and radial growth are 0.46, 0.42, 0.72, and 0.42 for 3-4 years, 5-6 years, 7-8 years, and 11-12 years, respectively.

For the upland population, different trees produced significantly different numbers of rooted stem cuttings which ranged from 83 percent to 8 percent rooted cuttings per tree. Because of high correlations between number of main roots per cutting and length of the longest main roots per cutting (r = 0.82), between number of main roots per cutting and number of rooted cuttings per tree (r = 0.85), and between length of the longest main root per cutting and number of rooted cuttings per tree (r = 0.85), it appears that trees which produce more rooted cuttings also produce rooted cuttings with longer roots and more main roots per cutting.

Significantly different numbers of rooted cuttings were produced among the six different hormone treatments. The two treatments using 1 percent IAA or 0.8 percent IBA on a girdled stem appear to give the best results being the only treatments which exceeded the girdled control treatment. The different treatments had no significant effect on the number of main roots per cutting or the length of the longest main root per cutting.

CHAPTER VI

RECOMMENDATIONS

I. Application of Results

The information obtained in this study does not completely support the hypothesis that there are two different populations of sycamores, upland and bottomland. In relation to wood properties, a significant difference between sites occurred in all six segments for fiber length and in four of the six segments for extractives. However, when weighted values for each wood property were calculated for each tree, the between-site differences were significant only for fiber length.

In order to more closely determine whether two populations of sycamores do indeed occur, a progeny test must be established using mother trees from both sites. Replicated tests should be established on upland and bottomland sites. This type of test will determine whether there are genetic differences in the upland trees which enable them to survive on these harsh sites; also, it will indicate to what degree the significant differences observed among upland trees are inherited and make it possible to estimate gains from a selection breeding program.

Adequate natural variation occurs among individual trees in specific gravity and fiber length to allow substantial gains to be made in improving these wood characteristics. Extractives has some variation among trees, but this variation is significant only for the first six years of growth. If extractives were a substantial problem, however, some reduction in their content may be obtained.

Since a positive and significant relationship exists between growth rate and extracted specific gravity for the upland trees, a good possibility exists for increasing specific gravity by increasing growth rate on these upland sites. Several questions remain in relation to this problem. It is not clear whether this relationship holds true for increases in growth rate due to irrigation, fertilization, or thinning of the three methods combined. However, it has been demonstrated (Saucier and Ike, 1969a and 1969b) that increases in growth rate obtained by fertilization and thinning of sycamore do not decrease specific gravity of trees growing on bottomland sites. Therefore, it is recommended that any of the several methods which are economically feasible to increase growth rate be utilized unless further research proves that such practices result in serious deterioration of wood properties.

The genetic base of the breeding population must be broadened by selecting more upland sycamores. A minimum of 30 superior trees should be selected from a larger number of selections in order to have a sufficient genetic base.

Rooted cuttings from the selected upland sycamores should be established in a breeding orchard as soon as possible. This orchard could then serve four purposes: (1) clonal test, (2) mother trees for production of controlled crosses, (3) a commercial source of material for rooted cuttings, and (4) a commercial source of first generation seed.

Both clonal tests and control-pollinated tests should be established to investigate the presence of dominance and epistasis in addition to additive gene action for economic properties such as height growth, diameter growth, specific gravity, fiber length, straightness, and pruning. If broad sense heritability is much greater than narrow sense heritability, the use of clonal material will be necessary to take advantage of the genetic variation in the species. This chance for improvement using clonal material must be large in order to offset the increase in cost involved in producing rooted cuttings. A decision to use clonal material in commercial plantations will require a greater number of selections than the 30 trees originally suggested. Many of the original selections will have poor rooting ability and will have to be discarded for commercial use; other selections will be eliminated because of poor performance in clonal tests.

II. Recommendations for Future Research

Some questions appeared during this study which may deserve further investigation. One question of interest is the reason for a significant negative correlation between average extractives for the first 12 years and the total age of the tree at breast height. This finding is contrary to those obtained from studies of other diffuse-porous hardwoods and conifers.

Another interesting finding is that significant differences in extracted specific gravity between the two sites only occur from the tenth growth ring and farther outward. This observation should be tested further by locating a number of trees on both sites which are 40 to 50 years of age at breast height and doing a detailed analysis of the rings for all the trees.

The technique for rooting of mature stem cuttings of sycamore trees has room for improvement. Leaf drop during the mist bench procedure is a great problem which leads to the death of up to half of the cuttings after they have rooted. Some type of foliar spray may help in leaf retention and prevention of death. Also, the hormone treatment can still be improved by taking the best two or three treatments in this study, varying the concentrations and adding other substances such as sucrose and fungicides.

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APPENDIX

TABLE A-1. Mean Values for Wood Properties of the Upland and Bottomland Sycamore Populations.

Wood Property	Number of Observations	Mean Value Upland	Mean Value Bottomland
radial growth, 2 years	144	1.42 cm	1.44 cm
unextracted specific gravity	144	0.514	0.495
extracted specific gravity	144	0.495	0.479
extractives	144	0.0190 g/cc	0.0152 g/cc
fiber length	144	1.56 mm	1.69 mm
0-2 years radial growth	24	1.57 cm	1.85 cm
0-2 years unex. sp. gr.	24	0.490	0.469
0-2 years ex. sp. gr.	24	0.472	0.456
0-2 years extractives	24	0.0188 g/cc	0.0126 g/cc
0-2 years fiber length	24	1.35 mm	1.52 mm
3-4 years radial growth	24	1.56 cm	1.69 cm
3-4 years unex. sp. gr.	24	0.503	0.480
3-4 years ex. sp. gr.	24	0.484	0.456
3-4 years extractives	24	0.0187 g/cc	0.0146 g/cc
3-4 years fiber length	24	1.48 mm	1.64 mm
5-6 years radial growth	24	1.59 cm	1.55 cm
5-6 years unex. sp. gr.	24	0.509	0.493
5-6 years ex. sp. gr.	24	0.491	0.481
5-6 years extractives	24	0.0183 g/cc	0.0126 g/cc
5-6 years fiber length	24	1.57 mm	1.69 mm
7-8 years radial growth	24	1.39 cm	1.36 cm
7-8 years unex. sp. gr.	24	0.515	0.505
7-8 years ex. sp. gr.	24	0.497	0.489
7-8 years extractives	24	0.0180 g/cc	0.0159 g/cc
7-8 years fiber length	24	1.61 mm	1.72 mm

TABLE A-1. (continued)

Wood Property	Number of Observations	Mean Value	
		Upland	Bottomland
9-10 years radial growth	24	1.22 cm	1.17 cm
9-10 years unex. sp. gr.	24	0.529	0.508
9-10 years ex. sp. gr.	24	0.509	0.492
9-10 years extractives	24	0.0202 g/cc	0.0155 g/cc
9-10 years fiber length	24	1.66 mm	1.76 mm
11-12 years radial growth	24	1.18 cm	1.03 cm
11-12 years unex. sp. gr.	24	0.538	0.512
11-12 years ex. sp. gr.	24	0.518	0.492
11-12 years extractives	24	0.0200 g/cc	0.0201 g/cc
11-12 years fiber length	24	1.71 mm	1.80 mm
weighted unex. sp. gr.	42	0.522	0.501
weighted extractives	24	0.0191 g/cc	0.0157 g/cc
weighted fiber length	24	1.62 mm	1.72 mm

TABLE A-2. Range of Values for Wood Properties of the Upland and Bottomland Sycamore Populations.

Wood Property	Number of Observations	Range	
		Upland	Bottomland
radial growth, 2 years	144	0.42 cm-3.64 cm	0.44 cm-4.40 cm
unex. sp. gr.	144	0.367-0.615	0.394-0.613
ex. sp. gr.	144	0.356-0.596	0.387-0.603
extractives	144	0.0023 g/cc-0.0399 g/cc	0.0002 g/cc-0.0311 g/cc
fiber length	144	1.13 mm-1.90 mm	1.26 mm-2.10 mm
0-2 years radial growth	24	0.49 cm-3.39 cm	0.45 cm-4.40 cm
0-2 years unex. sp. gr.	24	0.367-0.603	0.394-0.548
0-2 years ex. sp. gr.	24	0.356-0.587	0.387-0.538
0-2 years extractives	24	0.0111 g/cc-0.0358 g/cc	0.0026 g/cc-0.0217 g/cc
0-2 years fiber length	24	1.13 mm-1.73 mm	1.26 mm-1.77 mm
3-4 years radial growth	24	0.50 cm-3.63 cm	0.79 cm-3.14 cm
3-4 years unex. sp. gr.	24	0.453-0.610	0.394-0.586
3-4 years ex. sp. gr.	24	0.436-0.583	0.394-0.563
3-4 years extractives	24	0.0105 g/cc-0.0316 g/cc	0.0002 g/cc-0.0239 g/cc
3-4 years fiber length	24	1.22 mm-1.71 mm	1.43 mm-1.82 mm
5-6 years radial growth	24	0.56 cm-3.64 cm	0.76 cm-2.41 cm
5-6 years unex. sp. gr.	24	0.447-0.615	0.406-0.552
5-6 years ex. sp. gr.	24	0.434-0.596	0.405-0.535
5-6 years extractives	24	0.0094 g/cc-0.0312 g/cc	0.0011 g/cc-0.0237 g/cc
5-6 years fiber length	24	1.41 mm-1.77 mm	1.48 mm-1.87 mm
7-8 years radial growth	24	0.76 cm-3.59 cm	0.44 cm-2.63 cm
7-8 years unex. sp. gr.	24	0.463-0.604	0.440-0.560
7-8 years ex. sp. gr.	24	0.447-0.585	0.431-0.537
7-8 years extractives	24	0.0100 g/cc-0.0326 g/cc	0.0069 g/cc-0.0259 g/cc
7-8 years fiber length	24	1.41 mm-1.77 mm	1.56 mm-1.87 mm

TABLE A-2. (continued)

Wood Property	Number of Observations	Range	
		Upland	Bottomland
9-10 years radial growth	24	0.75 cm-2.22 cm	0.45 cm-2.61 cm
9-10 years unex. sp. gr.	24	0.448-0.595	0.438-0.613
9-10 years ex. sp. gr.	24	0.435-0.567	0.428-0.603
9-10 years extractives	24	0.0023 g/cc-0.0323 g/cc	0.0084 g/cc-0.0282 g/cc
9-10 years fiber length	24	0.47 mm-1.88 mm	1.58 mm-2.10 mm
11-12 years radial growth	24	0.42 cm-2.52 cm	0.47 cm-2.12 cm
11-12 years unex. sp. gr.	24	0.483-0.613	0.460-0.585
11-12 years ex. sp. gr.	24	0.471-0.595	0.442-0.555
11-12 years extractives	24	0.0105 g/cc-0.0300 g/cc	0.0093 g/cc-0.0311 g/cc
11-12 years fiber length	24	1.43 mm-1.90 mm	1.59 mm-1.99 mm
weighted unex. sp. gr.	24	0.481-0.599	0.453-0.562
weighted extractives	24	0.0135 g/cc-0.0273 g/cc	0.0094 g/cc-0.0205 g/cc
weighted fiber length	24	1.49 mm-1.81 mm	1.59 mm-1.88 mm

TABLE A-3. Mean Values for Weighted Wood Properties of the Upland and Bottomland Sycamore Populations by Trees.

Tree	Site	Number of Observations	Mean Value Unex. Sp. Gr.	Mean Value Extractives	Mean Value Fiber Length
I-1	Upland	2	0.508	0.0147 g/cc	1.75 mm
I-2	Upland	2	0.517	0.0189 g/cc	1.57 mm
I-3	Upland	2	0.516	0.0219 g/cc	1.55 mm
I-5	Upland	2	0.511	0.0164 g/cc	1.51 mm
I-7	Upland	2	0.508	0.0173 g/cc	1.65 mm
I-9	Upland	2	0.508	0.0177 g/cc	1.63 mm
I-10	Upland	2	0.496	0.0182 g/cc	1.62 mm
I-13	Upland	2	0.509	0.0176 g/cc	1.65 mm
I-18	Upland	2	0.577	0.0231 g/cc	1.66 mm
I-21	Upland	2	0.535	0.0305 g/cc	1.53 mm
I-22	Upland	2	0.543	0.0175 g/cc	1.64 mm
I-23	Upland	2	0.539	0.0158 g/cc	1.72 mm
LI-1	Bottomland	2	0.501	0.0180 g/cc	1.79 mm
LI-2	Bottomland	2	0.481	0.0103 g/cc	1.61 mm
LI-3	Bottomland	2	0.523	0.0202 g/cc	1.77 mm
LI-4	Bottomland	2	0.480	0.0181 g/cc	1.60 mm
LI-5	Bottomland	2	0.541	0.0145 g/cc	1.67 mm
LI-6	Bottomland	2	0.561	0.0201 g/cc	1.69 mm
LI-7	Bottomland	2	0.459	0.0109 g/cc	1.88 mm
LI-8	Bottomland	2	0.467	0.0129 g/cc	1.67 mm
LI-9	Bottomland	2	0.495	0.0163 g/cc	1.77 mm
LI-10	Bottomland	2	0.489	0.0151 g/cc	1.71 mm
LI-11	Bottomland	2	0.484	0.0139 g/cc	1.76 mm
LI-12	Bottomland	2	0.528	0.0181 g/cc	1.75 mm

TABLE A-4. Mean Values for Number of Main Roots per Cutting and Length of Longest Main Root Per Cutting for the 12 Selected Upland Sycamores.

Tree	Number of Observations	Number of Main Roots per Cutting	Length of Longest Main Root per Cutting
I-18	20	21.7	5.2 cm
I-23	14	18.2	5.1 cm
I-5	14	11.5	3.8 cm
I-3	13	15.3	3.4 cm
I-1	12	16.1	4.9 cm
I-2	12	7.3	2.5 cm
I-9	11	17.0	5.7 cm
I-21	8	3.3	2.3 cm
I-7	5	3.6	1.7 cm
I-22	3	8.2	1.6 cm
I-10	2	5.0	0.6 cm
I-13	2	1.5	0.3 cm

TABLE A-5. Number of Rooted Cuttings* by Hormone Treatment and Tree for Treatment Comparison Experiment with Sycamore.

Tree	Treatment** 1	2	3	4	5	6	Total
1	5	0	2	6	6	2	21
2	2	1	0	0	4	5	12
3	6	7	7	8	12	5	45
4	8	2	4	2	8	8	32
TOTAL	21	10	13	16	30	20	

*Twelve cuttings is the maximum possible in each cell.

**Treatment:
1. 0.8 percent IBA;
2. Hare's treatment;
3. 0.8 percent IBA + 10 ppm ethrel;
4. Hare's treatment + 10 ppm ethrel;
5. 1 percent IAA;
6. check-girdle only.

TABLE A-6. Mean Values for Number of Main Roots per Cutting by Hormone Treatment and Tree for Treatment Comparison Experiment with Sycamore.

Tree	Treatment* 1	2	3	4	5	6	Mean
1	5.2	6.2	**	2.5	9.5	17.5	8.2
2	8.7	2.0	15.0	**	**	6.8	8.1
3	2.7	10.5	9.0	6.4	15.1	1.4	7.5
4	7.1	14.4	26.5	4.0	2.0	5.9	10.0
Mean	5.9	8.3	16.8	4.3	8.9	7.9	

*Treatment:
1. 0.8 percent IBA;
2. Hare's treatment;
3. 0.8 percent IBA + 10 ppm ethrel;
4. Hare's treatment + 10 ppm ethrel;
5. 1 percent IAA;
6. check-girdle only.

**No cuttings rooted.

TABLE A-7. Mean Values for Length (cm) of Longest Main Root per Cutting by Hormone Treatment and Tree for Treatment Comparison Experiment with Sycamore.

Tree	Treatment* 1	2	3	4	5	6	Mean
1	1.4	3.8	**	1.3	2.5	2.3	2.3
2	5.5	2.1	11.2	**	**	4.0	5.7
3	3.4	8.3	5.9	4.8	9.7	3.2	5.9
4	1.3	2.2	6.5	1.3	0.8	0.8	2.1
Mean	2.9	4.1	7.9	2.5	4.3	2.6	

*Treatment:
1. 0.8 percent IBA;
2. Hare's treatment;
3. 0.8 percent IBA + 10 ppm ethrel;
4. Hare's treatment + 10 ppm ethrel;
5. 1 percent IAA;
6. check-girdle only.

**No cuttings rooted.

VITA

George Samuel Foster, Jr., was born in Arlington, Virginia, on October 19, 1952. In 1956, his family moved to Knoxville, Tennessee, where he graduated from Doyle High School in 1970 and from The University of Tennessee in 1975 with a Bachelor of Science degree in Forestry.

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