WOOD PROPERTY VARIATION AMONG FORTY-EIGHT FAMILIES OF AMERICAN SYCAMORE[1]

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ABSTRACT

American sycamore (*Platanus occidentalis* L.) progeny from forty-eight half-sib families representing five geographic seed sources were analyzed at the end of the fifth growing season for variation in wood properties and growth rate. Stem analysis revealed that specific gravity increased towards the top of the tree while fiber length first increased and then decreased as a function of height within the stem. Diameter, height, volume, specific gravity, fiber length, and moisture content showed significant differences between families. Height and moisture content were the only traits that did not exhibit significant variation due to seed source. Wood properties exhibited considerably less variation than did the growth parameters. However, wood properties did exhibit a larger component of variance due to family effects than did the growth parameters. Diameter, height, and volume were positively correlated with specific gravity and fiber length.

Keywords: Wood quality, specific gravity, fiber length, moisture content, progeny test, growth rate, *Platanus occidentalis* L.

INTRODUCTION

To meet the demand for fiber by the pulp and paper industry, large hectarages of hardwood plantations are being established on bottomland sites and other locations not suitable for pine. American sycamore (*Platanus occidentalis* L.) possesses a rapid growth rate, desirable wood properties, and appropriate silvical characteristics that lend it to large-scale plantation management (Farmer 1973). Of great importance to an intensive culture program is the selection of superior genotypes to improve such characteristics as wood fiber yield, quality, and uniformity. The existence of variation in the natural population is the key to genetic improvement. Superior phenotypes selected from natural populations are used to establish progeny tests. These tests are designed to identify the true genetic potential of the selected parents by evaluating their progeny under uniform environmental conditions.

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Patterns of variation in sycamore growth rate and wood properties have been identified by several authors. Cannon (1973), following the procedures of Duff and Nolan (1953), analyzed the horizontal, vertical, and oblique sequences of within-tree specific gravity variation for 12-year-old, plantation-grown sycamore. Specific gravity was found to increase with cambial age and to decrease from the base upwards in the stem when wood formed during the same year was analyzed. However, specific gravity of wood formed by cambia of the same age, i.e., in the same ring from the pith, increased from the bottom to the top of the tree. In contrast, Taylor (1969) found no relationship between specific gravity and sampling height within the stems of six mature sycamore trees.

Significant differences in height, diameter, volume, and specific gravity among families of sycamore have been reported (Webb et al. 1973; Nebgen 1980; Land 1981a; Patterson 1981). Sycamore fiber length was also found to differ among trees and at various heights within a tree by Taylor (1969). Huber and Bongarten (1981) found significant differences in fiber length among sixty-four families of sycamore. Lee (1972) discovered that while sycamore fiber length varied greatly among trees, the greatest variation existed among individual fibers within growth ring segments. Significant variation in sycamore wood moisture content among trees and among families has also been reported (Patterson 1981).

The existence of significant correlations between growth rate parameters and wood properties indicates that simultaneous improvements in both areas and/or indirect selection for a single trait may be feasible in a breeding program. Misconceptions about the effect of growth acceleration on wood properties exist as a result of: (1) the species dependency of this phenomenon, (2) the lack of sufficient knowledge of wood property variation, and (3) improper comparisons of wood of different ages.

Positive but weak correlations among growth rate parameters and specific gravity of plantation-grown sycamore have been reported by Webb et al. (1973), Nebgen (1980), and Patterson (1981). In contrast, studies of mature natural sycamore stands have revealed no significant relationship between growth rate and specific gravity (Taylor 1969; Land and Lee 1981). In an analysis of coppice sycamore, a negative correlation existed between volume growth and specific gravity (Huber and Bongarten 1981). Lee (1972) discovered a significant positive correlation between fiber length and growth rate.

The above literature provides evidence that variation in sycamore growth rate and wood properties is present in a sufficient degree to make genetic selection feasible. The presence of such variation justifies the investigation of other populations. The objectives of this study were: (1) to analyze a sycamore progeny test for variation in growth rate and wood properties, and (2) to examine the relationship between growth rate and wood properties.

MATERIALS AND METHODS

Westvaco Corporation established a sycamore progeny test in 1976 on Island Number Three on the Mississippi River in Carlisle County, Kentucky. The test population consists of forty-eight half-sib families representing five geographic seed sources: North Mississippi, South Mississippi, West Kentucky, Alabama, and South Carolina. The families also represent two levels of parental selection. Twenty-six of the families are progeny from nongraded seed trees, while the remaining twenty-two families are graded-selects from seed orchards and select trees. Seedlings from each of the forty-eight families were planted in ten-tree row plots at a 3.35- × 3.35-m spacing. Six replications of this planting were established.

At the end of the fifth growing season, the progeny test was thinned to five residual trees per row plot at uniform spacing. From those to be thinned, six trees were selected per family for growth rate and wood property analysis. Sample trees were representative of the range in height and diameter for the particular families. No trees from border rows or with obvious defects were selected. After felling at ground level, total tree height was measured, and stem sections, approximately 25 cm in length, were removed at breast height (1.4 m) from each tree. Fourteen of the 288 sample trees were randomly selected for stem analysis. Stem sections were removed from the base and at intervals of one-sixth total tree height along their stems.

Three cross-sectional discs, approximately 2 cm thick, were sawn from the center of each stem section. The first, a defect-free disc with bark intact, was used to determine moisture content on a dry weight basis and diameter inside bark. A ninety-degree, debarked, defect-free wedge was removed from the second sample disc for specific gravity determination. Specific gravity was calculated on a green volume, oven-dry weight basis.

Equations were calculated to estimate weighted specific gravity and moisture content employing the method of Wahlgren et al. (1966) and results of the stem analysis. In addition, a total stem volume equation was calculated by the confined regression technique of Belanger (1973).

A sliver of wood, approximately 0.5 cm in thickness, representing the entire fifth growth increment, was removed from the third cross-sectional disc for fiber length measurement. Fiber maceration of each sample was performed according to the method of Franklin (1946). Fibers were stained and mounted on microscope slides according to the procedures of Echols (1958). The projection instrument utilized for fiber length determination was an ampliscope. Two slides were prepared for each sample tree. Twenty-five whole fibers were measured on each of the two subsamples using a Panasonic digital mapwheel. Sample fibers were those that crossed one of two horizontal lines imposed on the screen of the ampliscope. The distance between these lines corresponded to the length of the longest fiber encountered during preliminary examination. If the average fiber lengths of the two subsamples differed by less than 5%, the average of all fifty fibers was accepted. If this level of precision was lacking, additional slides were prepared and measured until such precision was obtained. This subsampling procedure was adapted because of the large variation in length among fibers discovered during preliminary examination and also observed by Bergman (1949) and Lee (1972).

Statistical analysis was performed using a nested factorial model with families nested within seed sources to determine seed source, family, replication, and interaction effects. Separate analyses were employed to assess both the effects of within-tree variance and those due to level of parental selection. Duncan's multiple range tests were used to further analyze within-tree and seed source variation.

RESULTS AND DISCUSSION

Stem analysis

Because of within-tree variation in specific gravity of young sycamore trees (Cannon 1973), breast height sampling may provide an inaccurate estimation of

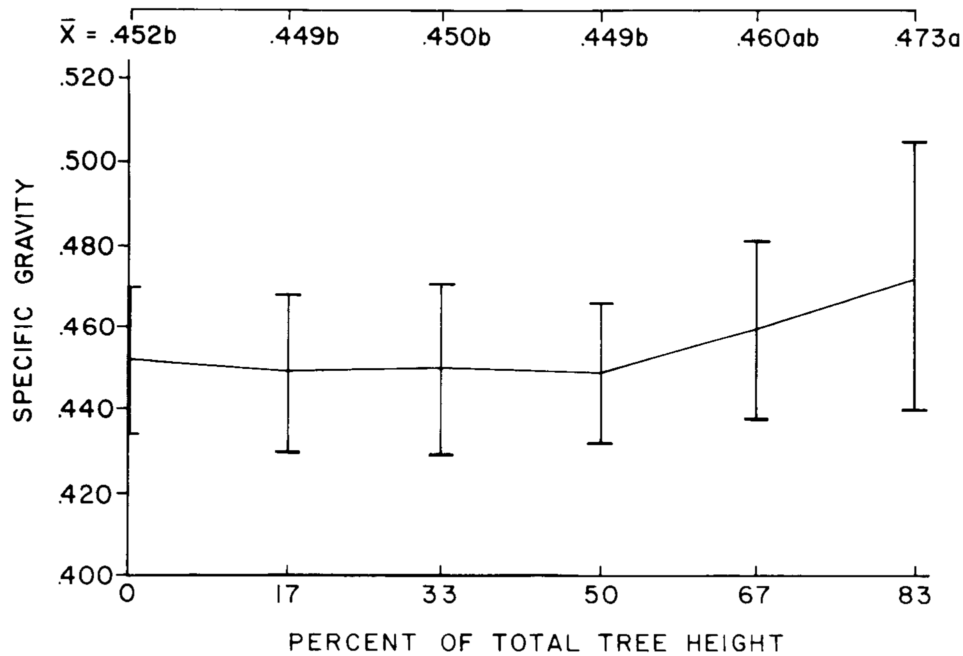

FIG. 1. Within-tree variation in specific gravity as a function of total tree height. Standard deviations are represented by vertical lines. Means with the same letter are not statistically different at the 5% level of probability.

the average specific gravity of the merchantable portion of the tree. Therefore, the following equations were derived for determining weighted or whole tree specific gravity (WSG) and moisture content (WMC):

$$WSG = 0.0923 + 0.8005SG_{bh} \quad r^2 = 0.78 \tag{1}$$

$$WMC = 35.4223 + 0.6739MC_{bh} \quad r^2 = 0.67 \tag{2}$$

where SG_{bh} and MC_{bh} are specific gravity and moisture content at breast height. Because of the uniform nature of the sample trees, multiple regression equations including such variables as diameter and height did not provide a significant improvement over simple regression. The difference between average breast height specific gravity (0.441) and average weighted specific gravity (0.445) was approximately 1%. Likewise, average breast height moisture content (115) and weighted moisture content (113) differed by only 2%. Therefore, breast height specific gravity and moisture content values can accurately predict weighted or whole-tree values when averaging large numbers of young sycamore trees.

Total stem volume (VOL) in cubic decimeters was predicted using:

$$VOL = 0.0407(DBH^2)(HT)r^2 = 0.97 \tag{3}$$

where DBH is diameter inside bark at breast height in cm and HT is total tree height in m. Utilization of Eq. (3) yields a volume that is approximately 10% greater than that obtained using the equation of Belanger (1973) derived from 103 randomly selected, 11-year-old plantation-grown sycamore in Georgia. This

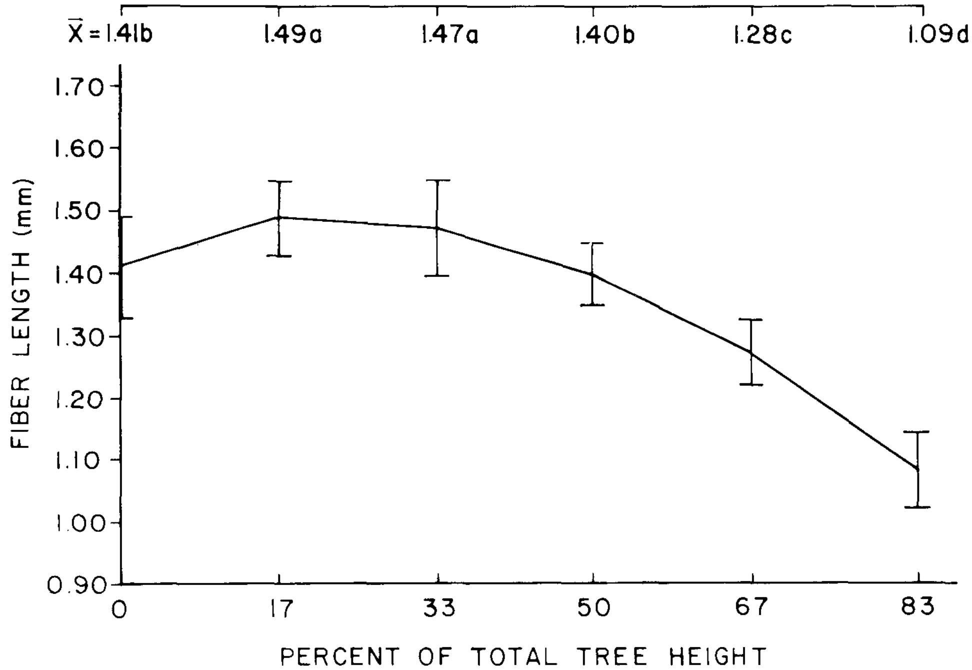

FIG. 2. Oblique sequence of within-tree fiber length variation. Standard deviations are represented by vertical lines. Means with the same letter are not statistically different at the 5% level of probability.

difference can be attributed to the effect of age and spacing on tree morphology and different methods of diameter measurement. This sizable discrepancy in calculated volume indicates the error that may occur when applying equations derived from one population to an unrelated population, and it emphasizes the need for the development of local and regional volume and yield tables for sycamore and other intensively cultured hardwoods.

Within-tree variation

Variation in wood specific gravity as a function of height within the stem is represented in Fig. 1. Statistical analysis reveals that there is a significant increase in specific gravity at the upper two sampling locations. This difference is indicated by the mean values appearing at the top of Fig. 1. This trend agrees with the findings of Cannon (1973) for 11-year-old plantation-grown sycamore, while contrasting with the findings of Land et al. (1983) for six-year-old sycamore in which specific gravity was found to decrease from the bottom to the top of the stem. Taylor (1969) and Lee (1972) found no meaningful relationship between specific gravity and sample height within the stems of mature natural sycamore trees. An increase in specific gravity at points high in the stem was noted by Larson (1962) who attributed this variation to the inclusion of greater proportions of high-density knots in the wood of the upper crown and/or the presence of larger amounts of tension wood.

The oblique or Type 1 sequence (Duff and Nolan 1953) of within-tree fiber length variation is given in Fig. 2. This sequence represents material formed during

TABLE 1. *Mean values, individual tree and family ranges and coefficients of variation (CV) for growth and wood properties of 5-year-old American sycamore.*

Trait	Mean	Individual tree range	CV	Family range	CV
Diameter breast height (cm)	8.77	3.51–15.60	18.94	6.62–11.19	11.09
Total tree height (m)	8.08	4.85–10.55	10.76	6.70–9.18	4.70
Volume (dm^3)	27.68	2.80–85.75	45.17	14.23–46.38	27.67
Specific gravity	0.445	0.402–0.507	3.92	0.420–0.477	2.70
Fiber length (mm)	1.54	1.31–1.84	5.06	1.45–1.67	3.38
Moisture content (%)	113	90–134	4.78	103–122	3.36

the same year (age five) at varying heights within the stem. The observed trend is similar to that reviewed by Dinwoodie (1961) for many tree species. Fiber length increases significantly from the base of the stem (1.41 mm) to a maximum (1.49 mm) that roughly corresponds to the base of the live crown and then decreases sharply to the top of the tree (1.09 mm). No significant relationship existed between moisture content and sample height within the stem in contrast to the findings of Kellison and Zobel (1971).

The increase in specific gravity and decrease in fiber length in the upper portions of the stems are not particularly important from a standpoint of utilization because of the low percentage of total stem volume accounted for by this material in trees of this age. A within-tree sampling procedure that weights the sampling towards the merchantable portion of the stem (Oleson 1973) may prove to be of greater value in the study of within-tree wood property variation.

Variation among families and seed sources

Diameter at breast height, total tree height, and volume averaged 8.77 cm, 8.08 m, and 27.68 dm^3, respectively (Table 1). Individual tree and family coefficients of variation (CV) for volume (45.17 and 27.67, respectively) are more than twice as great as those for diameter (18.94 and 11.09, respectively). Similarly, diameter exhibited approximately twice the variation expressed for total tree height. Mean values for specific gravity, fiber length, and moisture content were 0.445, 1.54 mm, and 113%, respectively. Individual tree and family ranges for the three wood

TABLE 2. *Analysis of variance for growth and wood properties for 5-year-old American sycamore.*

Source of variation	Degrees of freedom	Mean square					
		DBH	HT	VOL	SG[1]	FL	MC
Source	4	18.16**	6.84	1,069.09*	2.4980*	0.0325*	187.00
Family (source)	43	4.83*	1.89**	293.96**	0.7699**	0.0148**	97.20*
Replication	4	21.89**	18.89**	1,523.57**	0.5107	0.0355**	185.82*
Replication × source	14	2.83	2.04*	179.30	0.4076	0.0036	69.82
Replication × family (source)	78	2.74	0.93	153.56	0.2745	0.0073	56.30**
Tree [family (source) × replication]	144	2.76	0.76	156.36	0.3055	0.0061	29.31

[1] Divide by 1,000 for actual values.
* Significant at $\alpha = 0.05$; ** Significant at $\alpha = 0.01$.

TABLE 3. *Percent of total variation in growth and wood properties due to differences among sources, families, trees, and replications.*

Trait	Source	Family	Tree	Replication
	(percent)			
Diameter breast height	7.03	8.35	73.87	10.63
Total tree height	0.00	8.89	54.98	24.49
Volume	6.74	9.43	71.13	12.69
Specific gravity	7.76	19.30	72.79	0.14
Fiber length	4.22	15.48	73.07	7.22
Moisture content	0.33	12.25	55.14	4.17

properties were much narrower than for the growth parameters, resulting in coefficients of variation of 5% or less.

Differences in height (HT), volume (VOL), specific gravity (SG), and fiber length (FL) among families within seed sources were significant at the 1% level (Table 2). Diameter (DBH) and moisture content (MC) were significantly different among families at the 5% level. This analysis indicates that genetic improvement in sycamore growth rate and wood properties may result from selection of superior families.

Among the five geographic seed sources, height and moisture content were the only traits that did not exhibit significant differences. Diameter differed among seed sources at the 1% level, while volume, specific gravity, and fiber length differences were significant at 5%. The progeny from North Mississippi, Alabama, and West Kentucky generally performed better than average, while those from South Carolina and South Mississippi exhibited below average diameter, volume, and specific gravity. The below average performance by these latter two progeny groups may have resulted from being planted too far from their natural range.

Specific gravity was the only trait that did not differ between replications. A significant replication × seed source interaction existed for height. This resulted from the large variation in height among replications due to microsite differences. However, the replication × family interaction for height was nonsignificant. The only other significant interaction was the replication × family effect for moisture content, which is unexplained.

By far the largest proportion of the total variation in all traits is that due to differences among individual trees (Table 3). This among-tree variation accounted for from 55% of the total variance for height and moisture content to more than 73% for diameter and fiber length. Variation due to family effects was greater than that due to seed source effects for all six traits. Proportional variation as a result of family effects for the three wood properties were substantially higher than those for the growth parameters. Specific gravity exhibited the largest components of variation due to family and seed source effects (19.30 and 7.76%, respectively), while exhibiting small replication effects (0.14%).

Another source of potential variation was that due to different levels of parental selection. Analysis of variance revealed that diameter was the only trait that differed significantly between the two groups of progeny, those from graded-select parents and those from nongraded seed trees. The difference in diameter was significant at the 5% level and actually indicated that progeny from the nongraded seed trees had significantly greater diameter (8.97 cm) than progeny from graded-select parents (8.53 cm). However, this difference in diameter was not large enough to reflect a significant difference in the mean volumes of the two progeny groups.

Correlations

Simple correlations among diameter, height, and volume were all high (r = 0.79 to 0.97). Nebgen (1980) and Webb et al. (1973) reported correlations among these traits in the range from 0.80 to 0.89 for plantation-grown sycamore. In mature natural sycamore stands (Land 1981b; Schmitt and Wilcox 1969), a much lower degree of correlation (0.43 to 0.53, respectively) was found between height and diameter. This reduced correlation between these two traits with increasing age is the result of diameter growth culminating later than height growth.

Positive correlations, significant at the 1% level, existed for diameter × specific gravity (0.23), diameter × fiber length (0.26), height × fiber length (0.29), volume × specific gravity (0.18), and volume × fiber length (0.26). Height × specific gravity (0.12) was significantly correlated at the 5% level. Respective coefficients of determination (r^2) ranged from 0.01 to 0.09, indicating that less than 10% of the variation in specific gravity or fiber length was accounted for by variation in growth rate.

Moisture content was negatively correlated with diameter (−0.13) at the 5% level. The only significant correlation among wood properties existed for specific gravity × moisture content (−0.57) at the 1% level, which agrees with the findings of Patterson (1981) for this same relationship (−0.58) in 5-year-old plantation-grown sycamore. No significant linear relationship existed between specific gravity and fiber length.

SUMMARY AND CONCLUSIONS

The presence of significant within-tree variation in wood specific gravity and fiber length illustrates the need to establish uniform sampling procedures and locations so that direct comparisons between experiments can be made. Results of the stem analysis indicate that weighted specific gravity can be predicted more accurately from breast height samples than can weighted moisture content. Comparison of the results from two volume equations revealed the need for the establishment of local and/or regional volume and yield tables for short-rotation sycamore.

Sufficient variation existed among families for height, diameter, and volume to suggest that substantial gains may be achieved through selection to improve wood fiber yield in sycamore. Although significant family differences existed for specific gravity, fiber length, and moisture content, these wood properties possessed a limited degree of variation between families. Therefore, selection for specific gravity, fiber length, or moisture content would probably result in only minor gains. The seed source analysis revealed that sycamore progeny that were moved long distances from their origin may perform poorly when compared with more local seed sources. The greatest potential gains should be achieved by selection of superior trees within families from the local seed sources.

Wood properties exhibited a larger component of variance accounted for by family effects than did the growth parameters. This may indicate that specific gravity, fiber length, and moisture content are under stronger genetic control than diameter, height, or volume. Little difference existed between progeny from graded-select parents and those from nongraded seed trees. Thus, significant gains over mass selection have yet to be achieved in sycamore breeding programs. Diameter, height, and volume were positively and significantly correlated with specific gravity and fiber length. Therefore, direct selection for growth rate may lead to small simultaneous improvements in wood quality. In comparing the results of this study with studies of mature natural sycamore populations, it is apparent that within-tree patterns of wood property variation and growth rate × wood property correlations may significantly change with increasing age.

REFERENCES

BELANGER, R. P. 1973. Volume and weight tables for plantation-grown sycamore. USDA For. Serv. Res. Paper SE-107. Southeast. For. Exp. Sta., Asheville, NC.

BERGMAN, S. T. 1949. Lengths of hardwood fibers and vessel segments. Tappi 32(1):494–498.

CANNON, G. P. 1973. Specific gravity variation in plantation-grown trees of *Platanus occidentalis* L. M.S. thesis, University of Georgia, Athens.

DINWOODIE, J. M. 1961. Tracheid and fiber length in timber: A review of the literature. Forestry 34:125–144.

DUFF, G. H., AND N. J. NOLAN. 1953. Growth and morphogenesis in the Canadian forest species. I. The control of cambial and apical activity in *Pinus resinosa* Ait. Can. J. Bot. 31:471–513.

ECHOLS, R. M. 1958. Variation in tracheid length and wood density in geographic races of Scots pine. Bull. No. 64, Yale Univ. School of Forestry, New Haven, CT.

FARMER, R. E., JR. 1973. Decision making for development and use of genetically improved hardwoods. J. For. 71(2):75–78.

FRANKLIN, G. L. 1946. A rapid method of softening wood for microtome sectioning. Trop. Woods. 88:35–36.

HUBER, D. A., AND B. BONGARTEN. 1981. Specific gravity as a selection criterion in sycamore. Pages 320–327 in Proc. 16th South. For. Tree Improv. Conf., Blacksburg, VA, May 27–28.

KELLISON, R. C., AND B. J. ZOBEL. 1971. Wood specific gravity and moisture content of five hardwood species of the southern United States. Paper No. 3408. North Carolina State University Agriculture Experiment Station, Raleigh.

LAND, S. B., JR. 1981a. Genetic variation, heritabilities, and selection strategies for early growth of sycamore in the gulf south. Pages 123–135 *in* Proc. 16th South. For. Tree Improv. Conf., Blacksburg, VA, May 27–28.

———. 1981b. Stand characteristics and phenotypic variation for sycamore in the southern United States. Tech. Bull. No. 115, Mississippi Agricultural and Forest Experiment Station, Mississippi State.

———, AND J. C. LEE. 1981. Variation in sycamore wood specific gravity in the south. Wood Sci. 13(3):166–170.

———, S. G. DICKE, G. A. TUSKAN, AND P. E. PATTERSON. 1984. Genetic, site, and within-tree variation in specific gravity and moisture content of young sycamore trees. Tappi (in press).

LARSON, P. R. 1962. A biological approach to wood quality. Tappi 45(6):443–448.

LEE, J. C. 1972. Natural variation in wood properties of American sycamore (*Platanus occidentalis* L.). Ph.D. dissertation, North Carolina State University, Raleigh.

NEBGEN, R. J. 1980. Variation in, inheritance of, and correlations between a number of growth and form traits in three sycamore populations. M.S. thesis, Texas A&M University, College Station.

OLESON, P. O. 1973. The influence of the compass direction on the basic density of Norway spruce (*Picea abies* L.) and its importance for sampling for estimating the genetic value of plus trees. For. Tree Improv. No. 6. Arboretet. Akademisk Forlag, Kobenhavn.

PATTERSON, P. E. 1981. Genetic variation in wood and bark specific gravity of five-year-old sycamore in the gulf south. M.S. thesis, Mississippi State University, Mississippi State.

SCHMITT, D., AND J. R. WILCOX. 1969. Sycamore variation in the lower Mississippi Valley. USDA For. Serv. Res. Note SO-91. So. For. Exp. Sta., New Orleans, LA.

TAYLOR, F. W. 1969. Variation in wood properties of sycamore. Res. Rep. No. 7, Mississippi State University Forest Products Utilization Laboratory, Mississippi State.

WAHLGREN, H. E., A. C. HART, AND R. R. MAEGLIN. 1966. Estimating specific gravity of Maine conifers. USDA For. Serv. Res. Paper FPL-61 For. Prod. Lab., Madison, WI.

WEBB, C. D., R. P. BELANGER, AND R. G. MCALPINE. 1973. Family differences in early growth and wood specific gravity of American sycamore (*Platanus occidentalis* L.). Pages 213–227 *in* Proc. 12th South. For. Tree Improv. Conf., Baton Rouge, LA, June 12–13.