WOOD PROPERTY VARIATION OF MISSISSIPPI DELTA HARDWOODS

Fred W. Taylor
Mississippi Forest Products Laboratory, Mississippi State, Miss. 39762
and
Thomas E. Wooten
Clemson University, Department of Forestry, Clemson, S.C. 29631

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ABSTRACT

Variation in specific gravity, fiber length, fiber dimensions, and volumetric composition were investigated for selected heights and growth rings of five Mississippi Delta hardwood species: black willow, willow oak, sycamore, pecan, and sugarberry. Variation of specific gravity with age of the cambium was not only different from species to species, but was also different at different sampling heights. The fiber length-age relationship in study trees conformed to the general pattern of large increases in fiber length with age in rings near the pith, followed by a more gradual increase until a maximum was reached. Variations in fiber diameter were not great, but in all species, cell diameter decreased as height in the stem increased. Thin-walled fibers were found near the pith and thick-walled fibers developed in the outermost growth increments.

Volumetric composition data revealed large variations between sampling points. The general pattern with age was a linear or curvilinear increase in vessel volume with a corresponding decrease in fiber volume, while ray volume remained constant or increased slightly with age.

Correlation analysis was used to evaluate the interrelationships of measured properties in three different species (willow, sugarberry, and pecan). Wide growth rings in these species contained proportionately fewer vessels and more fibers than narrow growth rings as well as shorter fibers. High specific gravity was associated with increased fiber volume. However, the analysis showed no significant differences in specific gravity resulting from variations in growth rate.

Additional keywords: Salix nigra, Quercus phellos, Platanus occidentalis, Carya illinoensis, Celtis laevigata, specific gravity, fiber dimensions, vessel volume, ray volume, cell-wall thickness, height, ring number.

INTRODUCTION

Wood property variations within and among trees have come under rather close scrutiny in recent years. Interest has intensified as researchers have studied the relationships between wood and fiber qualities and their various end uses. The more notable, and perhaps more intensive, studies have involved the relationships between wood properties and pulp properties; and efforts have been devoted primarily toward using this knowledge to estimate wood quality of the existing timber supply or to establish tree-improvement programs aimed at altering wood properties in future generations. Softwoods have received the most attention, as evidenced by the wealth of literature on tracheid dimensions; however, increased demands for high quality hardwoods have stimulated studies of many hardwood species. Results of such investigations have been reviewed in other publications (deZeeuw 1965; Dinwoodie 1961; Spurr and Hyvarinen 1954; Taylor 1968a), and hence will not be repeated in this paper.

This report on the wood property variation of hardwoods is part of a continuing study of the anatomical, chemical, and mechanical properties of selected Mississippi Delta hardwood species. Objectives of the study are to increase existing knowledge of the variation encountered within and among trees, and to accumulate data that may be used both for estimating timber quality and for tree improvement programs.

SPECIES

The Mississippi Delta, 150 to 200 miles wide along the southern reaches, is a very fertile area containing alluvial deposits of topsoil as much as 50 feet deep in some areas. The fertile soil, long growing season, and well-distributed rainfall in the Delta combine to produce excellent growing conditions for the hardwood species that form the ecological climax vegetation of the area.

Study species were selected to: 1) include representatives of both ring and diffuse porous species; 2) represent species of special economic importance in the Mississippi Delta; and 3) supply information on species for which published data are limited. Species selected for study were:

1. Black willow (*Salix nigra* Marsh.).
2. Willow oak (*Quercus phellos* L.).
3. Sycamore (*Platanus occidentalis* L.).
4. Pecan (*Carya illinoensis* (Wangenh.) K. Koch).
5. Sugarberry (*Celtis laevigata* Willd.).

PROCEDURE

The study species were examined sequentially. Hence, there were slight differences in sampling procedures among species. For example, sampling height and sample rings varied slightly from species to species, and in one species (sugarberry), rings were numbered from bark to pith. The following procedure applies generally for each species.

Six dominant trees with relatively straight, erect trunks and well-formed crowns were selected for study. Study trees were growing on uniform sites in natural stands. Selected trees were felled, and short bolts were removed from the stem at 5, 10, 20, 30, etc., feet above ground. Cross-sectional discs, 1 inch in thickness, were cut from the bolts and used for the study of wood properties.

Specific gravity specimens were prepared by cutting four 10-degree wedges from pith to bark along each cardinal direction from one disc at each height. The specific gravity of each wedge was determined by measuring its green volume and oven-dry weight. A second disc from each height served as a source of material for incremental specific gravity determinations. Radial strips, ¾-inch in width and extending from pith to bark, were cut along the southern radius of each disc. Rings 3, 5, 9, 13, 18, 23, 28, etc., and the next-to-last ring at each height were selected for study. Study rings at each height were isolated, and their specific gravities were determined on a green-volume basis.

Following the measurement of individual-ring specific gravity, the study rings were macerated in a solution of glacial acetic acid and hydrogen peroxide. Macerated fibers were stained with acridine orange dye and their lengths were measured. The length-measurement technique used was a modification of the "graduated bull's eye target method" described by Wilson (1954). Lengths of 45 whole fibers were measured for each ring, using the selection technique described by Hart and Swindel (1967). Fiber diameter, fiber lumen diameter, and fiber wall thickness were measured with a wide-field filar micrometer. All measurements were made along the tangential axis of the fibers; thus fiber diameter and lumen diameter are measurements of tangential dimension, and fiber wall thickness is a measurement of the thickness of radial walls. Such measurements were made on 15 whole fibers from each individual ring.

A third disc from each height was used for studies of volumetric composition. Sections were removed from the southern radius, and tissue types were measured for the same rings used for fiber length determination. Rings to be examined were first saturated with water; then a smooth cut was made on the transverse surface and the specimen was stained with a 1:1000 aqueous solution of acridine orange. Stained sections were covered with a thin cover slip and examined with an ultro-pak objective at a magnification of 110×, using the proper light source and filters for in-

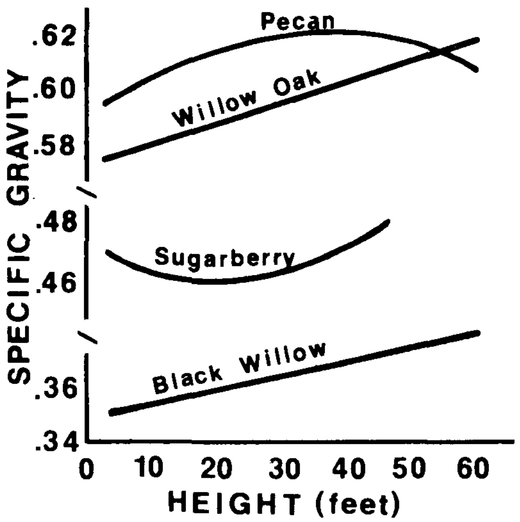

FIG. 1. Relationship of sampling height and average specific gravity for selected study species. Lines are based on best fitting mathematical equations.

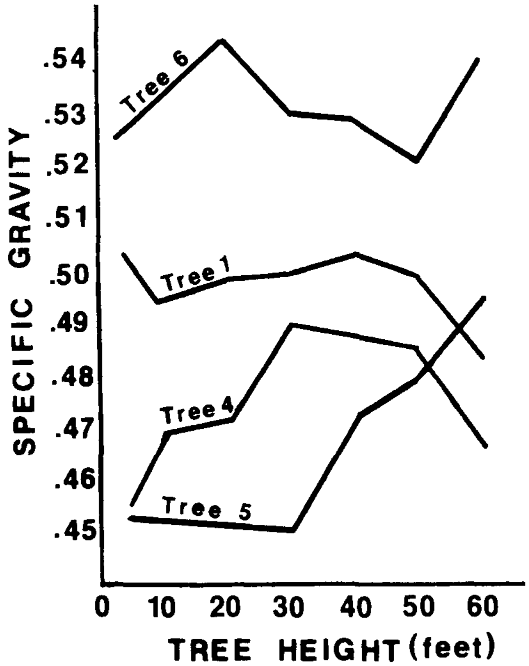

FIG. 2. Effect of tree height on the specific gravity of representative sycamore trees.

direct fluorescence microscopy. Volumetric composition measurements on study rings of black willow, willow oak, and sycamore were made with the aid of a Leitz integrating eyepiece used to accumulate measurements along a line transect as described by Taylor (1968b). Vessel, fiber, longitudinal parenchyma, and ray parenchyma volumes were recorded and the proportion of each, expressed as a percent of the total xylem volume, was calculated. Volumetric composition measurements for pecan and sugarberry consisted of a point-count technique employing a Zeiss integrating eyepiece with Graticule 1 (Test-Point Graduation).

RESULTS

As with procedure, there were slight differences in the method of analysis and the preparation of data for individual species. These differences preclude direct comparison of every property at complementary sampling points. The reader should, hence, recognize that some species will not be represented in some sections or in some figures. Also information was intentionally omitted from discussions and figures where it became superfluous or was not pertinent.

In this paper, results are reported under general headings to elucidate trends in wood property variations and call the reader's attention to comparisons and contrasts among the study species. Specific data and analysis procedures have been deleted in favor of graphs showing trends

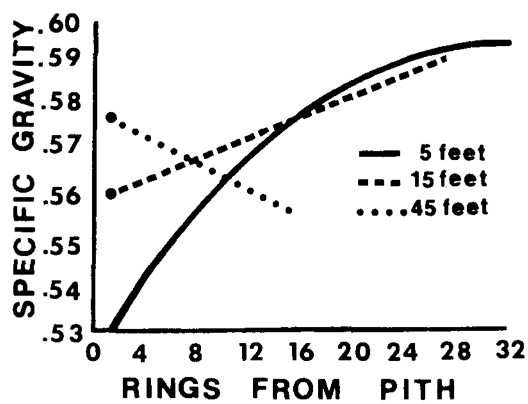

FIG. 3. Regression of specific gravity on rings from the pith for three vertical sampling positions in willow oak.

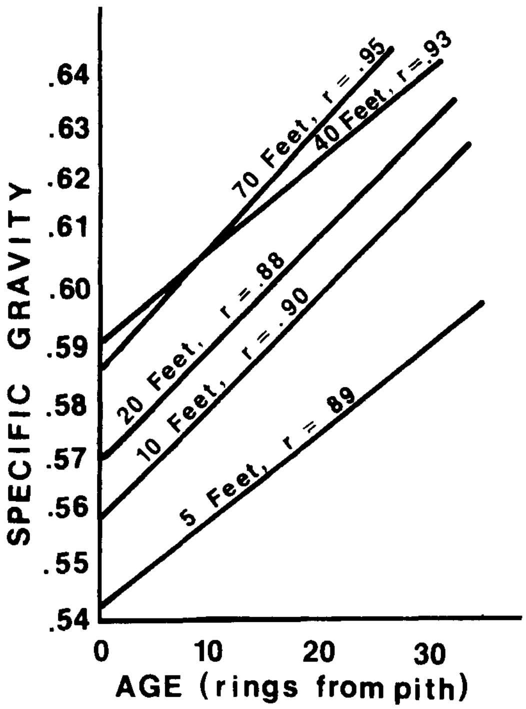

FIG. 4. The relationship of age and specific gravity at selected sampling heights in pecan. Lines were fitted by linear regression. Correlation coefficients are shown for each line.

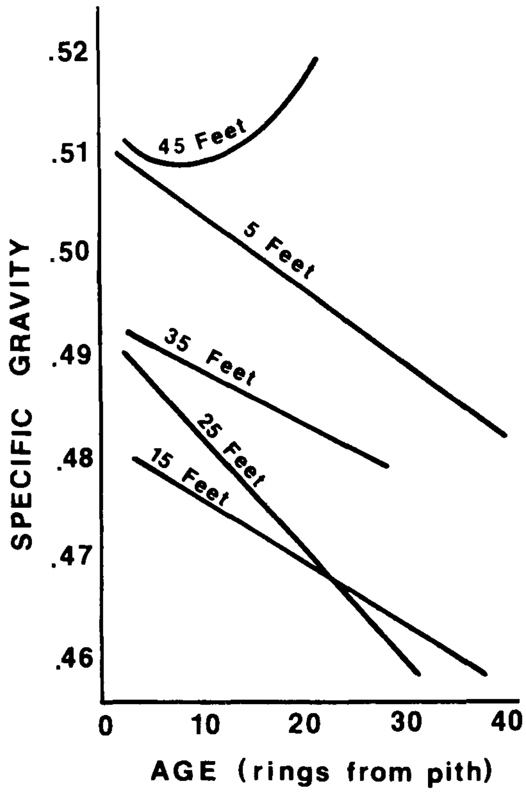

FIG. 5. The relationship of age and specific gravity at selected sampling heights in sugarberry.

for species and statements indicating that reported differences were or were not statistically significant. Research reports containing tabular data and greater detail about property variations of individual species are available from the Mississippi Forest Products Utilization Laboratory, Mississippi State University, Mississippi, 39762.

Specific gravity

The relationship between sampling height and specific gravity varies greatly from species to species. Therefore, no generalization about the effect of tree height on specific gravity is possible for the Delta hardwoods studied. Specific gravity increased linearly with tree height in both black willow, a diffuse porous species, and willow oak, a typically ring porous species (Fig. 1). The general trend in pecan was an increase in specific gravity from stump height to 20 feet with a relatively constant specific gravity at sampling heights higher in the stem. For sugarberry the trend was essentially reversed, i.e., specific gravity decreased sharply from breast height to 10 feet, varied randomly at mid-height, and, on the average, increased at the 45-foot sampling height.

An analysis of variance revealed that the differences in specific gravity with sampling height were statistically significant for the above species. However, only the large changes in specific gravity at different heights in the lower stem were significant in pecan and sugarberry. There was no significant difference in specific gravity at different sampling heights in sycamore (Fig. 2).

The pattern of variation for specific gravity (a property influenced by the size, proportion, arrangement, and wall thickness of wood elements) may be quite dif-

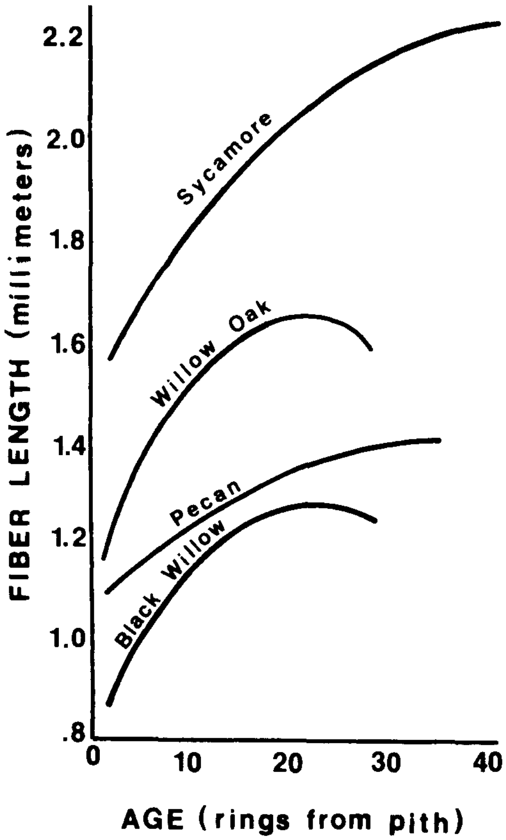

FIG. 6. The relationship of age and fiber length of selected Delta hardwoods. Curves are averages for all sample trees and heights of each species.

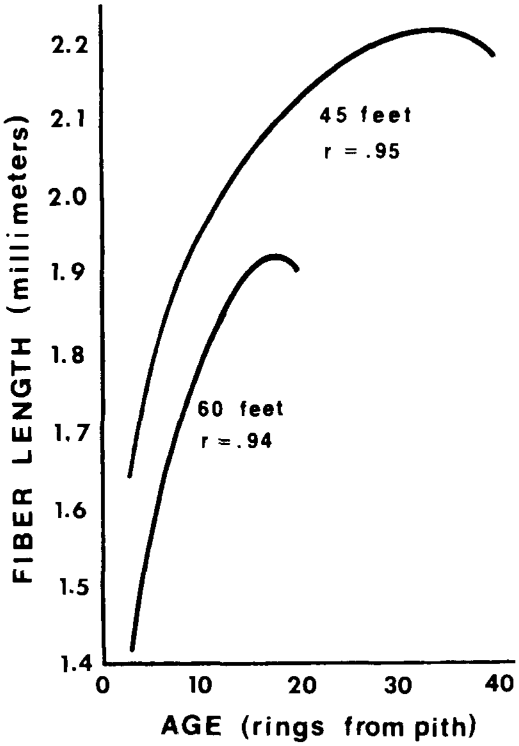

FIG. 7. The effect of age on the average fiber length of all sycamore trees at 4.5 and 60 ft.

ferent in different species. Panshin and deZeeuw (1970) list four distinct patterns of variation in hardwoods, ranging from an increase in specific gravity with age to a decrease. This study revealed that the relationship of specific gravity and age (rings from the pith) is not only different from species to species, but may be quite different at different sampling heights. This effect of height is clearly illustrated in the specific gravity variation of willow oak (Fig. 3), where specific gravity increased with age at the 5-foot sampling height and decreased with increasing age at a sampling height of 45 feet. Similar patterns of variation were found in black willow and sycamore. However, the specific gravity of pecan increased linearly at approximately the same rate for all sampling heights (Fig. 4).

The relationship of age and specific gravity was quite unusual in sugarberry. For sampling heights 5 through 35 feet, there was a linear decrease in specific gravity with increasing age, but at a sampling height of 45 feet the relationship was curvilinear, decreasing with age in rings near the pith and then increasing in wood formed in subsequent growth rings (Fig. 5). There is no obvious explanation for this anomalous relationship of specific gravity and age nor for the very high specific gravity at height 45 feet. However, the altered pattern of the specific gravity-age relationship at various sampling heights in other species (Gohre 1958; Taylor 1968a, 1969a; Wooten 1968; Wooten and Taylor 1968) encourages acceptance of the sugarberry data as a realistic variation pattern.

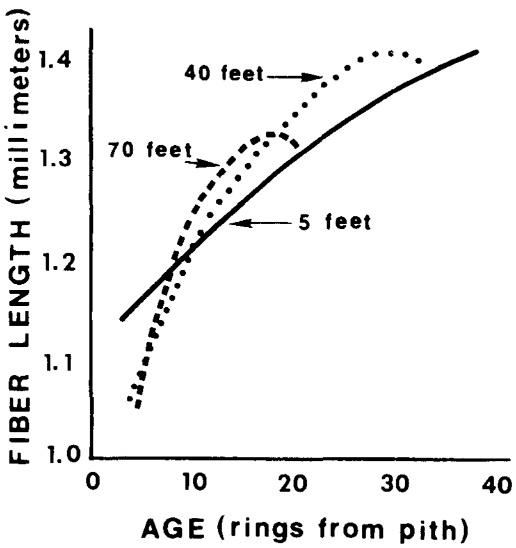

FIG. 8. The relationship of fiber length and age at different sampling heights in pecan.

One generalization can be made from the specific gravity data on the five study species; i.e., there are large specific gravity differences from tree to tree. In each species, an analysis of variance revealed that the among-tree differences were statistically significant. Impressive differences among sycamore trees are illustrated in Fig. 2. In each species, some individual trees were consistently high and other trees consistently low in specific gravity at every sampling point within the tree. Since there were no apparent environmental factors that would account for the differences among trees, a large part of the observed variation is attributed to the inherent potential of individual trees to produce higher or lower specific gravity wood than their neighbors.

Fiber dimensions

Length. Fiber length-age relationships based on the averages of 12,000 to 15,000 fiber length measurements in each of four species are illustrated in Fig. 6. These variation patterns, in which fiber length increases with age in rings near the pith followed by a more gradual increase until a maximum is reached, have been well documented for both hardwoods and softwoods

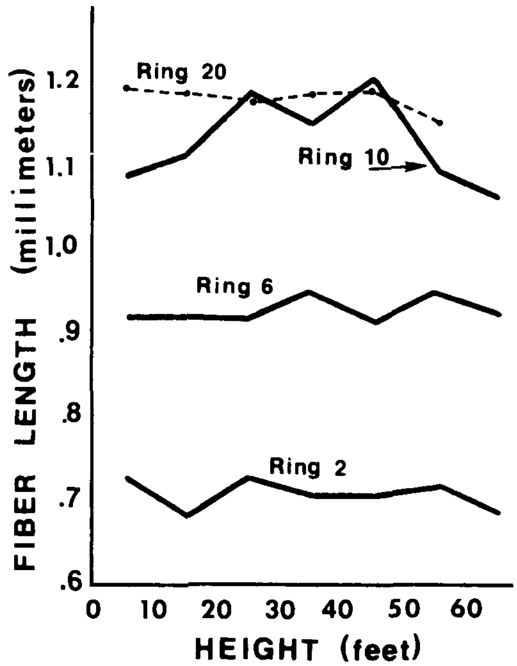

FIG. 9. Fiber length–height relationships for corresponding radial rings in black willow.

(Anderson 1951; Jackson 1959; Kaeiser 1956; Kennedy 1957).

The fiber length-age relationship was quite different at different sampling heights in pecan and sycamore but similar at successive heights in the other species. The general pattern of fiber-length increase with age held true for all heights in sycamore. However, the number of years through which fiber length increased was greater for sampling points lower in the stem (Fig. 7). Hence, the maximum fiber length attained was less at higher sampling points in the tree. In pecan, the fiber length increase with age was nearly linear from pith to bark at the 5-ft sampling height. At sampling points higher in the tree, fibers were quite short near the pith, increased rapidly during early years, and reached a maximum, or decreased, in length near the bark (Fig. 8).

Fiber length differences among heights are most evident when the many fiber measurements are weighted according to the amount of xylem tissue represented by

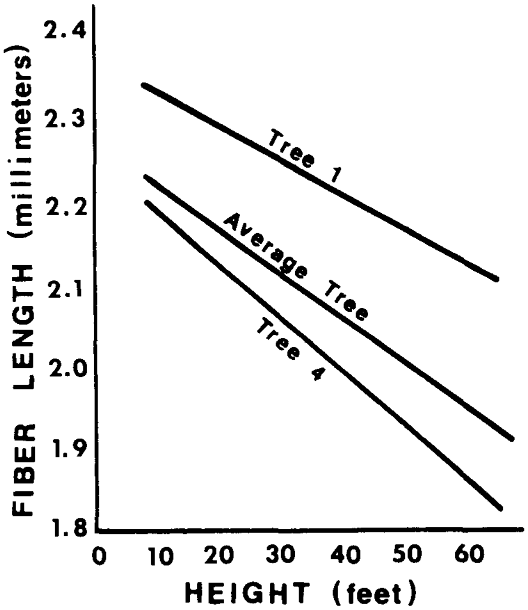

FIG. 10. Effect of height on weighted average fiber length of sycamore (values for breast-height and heights above 70 ft deleted).

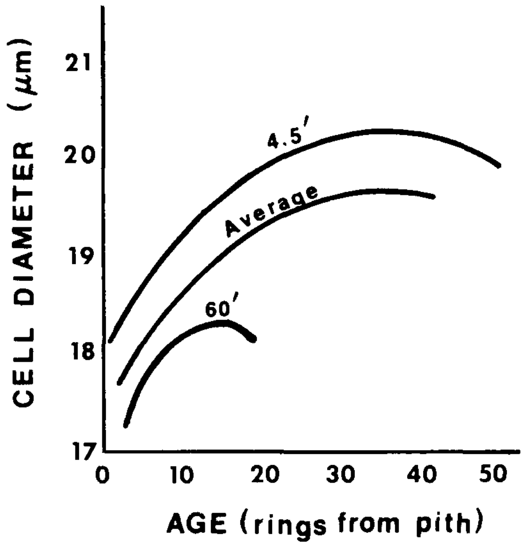

FIG. 11. Effect of age on average cell diameter for all trees and heights and for tree averages at height 4.5 and 60 ft in sycamore.

each fiber length sample. Weighted fiber lengths were significantly shorter at sampling points higher in the stem for black willow, sycamore, and sugarberry. For black willow, there was a decrease in average fiber length from 1.21 mm at the 5-ft level to 1.00 mm at the 75-ft level. This pattern was the result of a decrease in the number of radial sampling positions at higher sampling heights, notably the rings having the longer fibers; but there was also a decrease in fiber length of corresponding rings at increased heights in the stem that contributed to the reduction in fiber length with increased height. A typical example, that of black willow, is shown in Fig. 9. In sugarberry, the decrease in fiber length with height was small and obviously related to the relatively larger proportion of juvenile wood at sampling points higher in the tree. A graphic presentation of the weighted fiber length values for various sampling heights in sycamore shows how fiber length decreased as sampling height increased (Fig. 10). In pecan and willow oak, there was no significant change in fiber length at the various sampling heights.

As was the case with specific gravity, there were statistically significant differences in fiber length from tree to tree in each of the study species. It should be emphasized that this tree-to-tree difference in fiber length was present in morphologically similar phenotypes grown in similar environments.

Cell diameter and wall thickness. Cell diameter and wall thickness measurements were made on three of the species, black willow, willow oak, and sycamore.

The general pattern of fiber diameter change within a tree was an increase in age to a maximum, followed by a leveling off and a slight decrease in the outer rings. A representative pattern is shown in Fig. 11.

Cell diameter decreased with sampling height in each of the species evaluated. However, the maximum variation in fiber diameter was not great, and the largest average fiber diameter for a sampling position was only a few microns larger than the average fiber diameter at the sampling point with the smallest diameter fibers. This uniformity is evident in the weighted values reported by discrete heights for each sycamore tree (Table 1). For black willow, the average diameter of fibers in ring 2 varied from 20.68 μm at the 5-ft height to 16.52 μm at the 75-ft sampling height. In willow oak, the average fiber diameter increased by 2 to 3 μm from pith to bark at all heights. Average fiber diameters ranged from 13 to 14 μm near the pith and from 16 to 17 μm near the bark.

For each of the three species, minimum fiber-wall-thickness values were recorded near the pith and maximum values found for the outermost rings. The patterns for willow oak are illustrated in Fig. 12.

The magnitude of the radial changes varied with the species. For example, radial increases from pith to bark of approximately 0.20 μm were characteristic of all heights in willow oak, with values ranging from 3.3 to 3.7 μm. For black willow, the change was more pronounced, ranging from about 2.5 μm for the inner growth rings to about 3.6 μm for the outermost increments, irrespective of sampling height. Sycamore wall thicknesses varied from 2.7 to 4.1 μm, also with no significant height differences evident.

Volumetric composition

Measurement of the proportion of tissue types revealed large variations from sampling point to sampling point in most species studied. Vessel and fiber volumes were especially variable with ray parenchyma and longitudinal parenchyma values more constant throughout the trees of a given species.

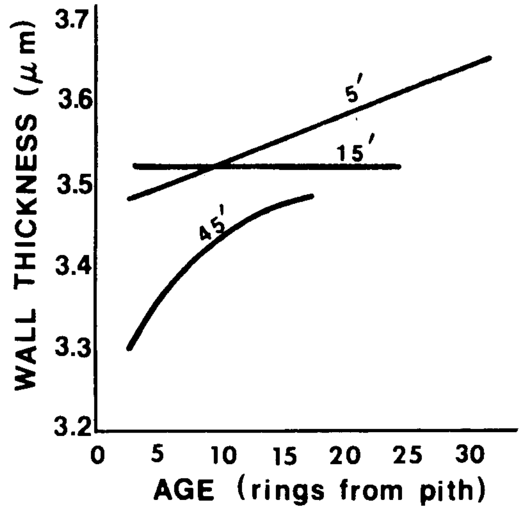

FIG. 12. Regression of fiber wall thickness on age for discrete sampling heights in willow oak.

An analysis of variance indicated that changes in vessel and fiber volume with height were significant in pecan, sycamore, and willow, but were possibly due to chance in willow oak and sugarberry. The pattern of variation was an increase in vessel volume and a decrease in fiber volume at

TABLE 1. *Weighted average fiber diameter for discrete heights of each sycamore tree*

Height (ft)	Tree Number 1	2	3	4	5	6	Numerical Average
	(µm)						
4.5	21.02	19.42	22.13	21.11	21.87	19.72	20.88
20	20.42	18.86	22.04	20.22	21.42	19.44	20.40
40	20.70	19.10	20.75	19.70	18.99	20.00	19.88
60	19.93	18.53	20.62	19.45	18.53	17.44	19.08
Numerical Average	20.53	18.98	21.38	20.12	20.20	19.16	

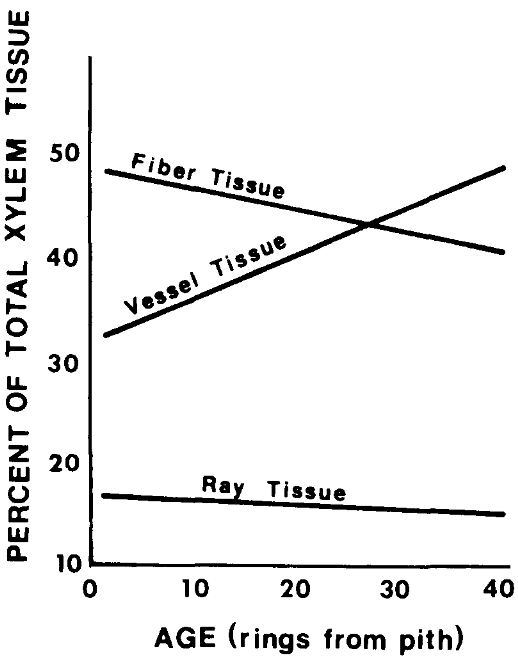

FIG. 13. Relationship of the age of the vascular cambium to the proportion of fibers, vessels, and rays formed in xylem tissue of sugarberry at breast height.

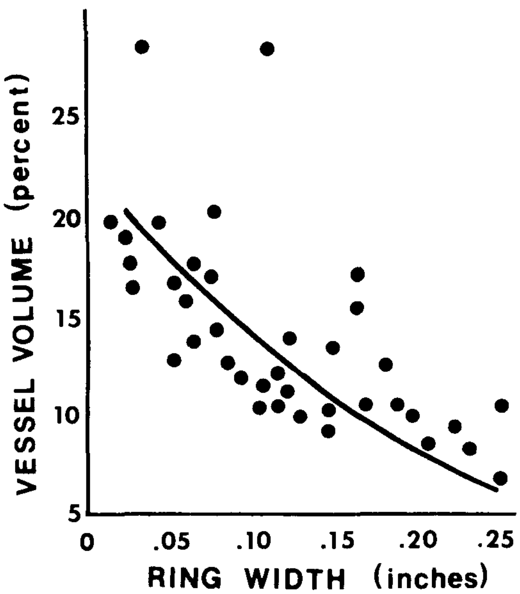

FIG. 14. The relationship of ring width and vessel volume in one pecan tree.

successive heights in the stem. Ray volume differences with height were statistically significant in pecan, where ray volume increased with sampling height, and in sugarberry, which showed a distinct decrease in ray volume from 5 ft to 15 ft.

The general pattern of change in volumetric composition with age was a linear or curvilinear increase in vessel volume and a corresponding decrease in fiber volume as the cambium aged, while ray volumes generally remained constant or increased slightly with age. An example, that of sugarberry, is illustrated in Fig. 13. Variations in the relative proportions of tissue types at sampling positions from pith to bark were unrelated to ring number in pecan, a species that did not conform to the general pattern of change with aging.

As with most wood properties, between-tree differences in volumetric composition were observed. These tree-to-tree differences in fiber and vessel volume were statistically significant in sycamore and pecan, two of the three species that were statistically analyzed for tree-to-tree differences. Ray volume variations were small, but statistically significant differences were detected in each species evaluated.

Interrelationships of properties

The association of various wood properties and their effect upon one another were evaluated by correlation analysis in three of the study species (black willow, sugarberry, and pecan). Because of the observed differences in properties among trees and at various heights in the stem, correlation coefficients were first determined for properties in each tree, then for specific heights, and finally for all trees and heights combined. A summary of simple correlation coefficients of sugarberry is presented in Table 2.

Correlations of ring width and specific gravity. Several authors have reported that fast growth rate in hardwoods is associated with high specific gravity. Other authors have, however, questioned the validity of the reported positive relationship between

TABLE 2. *Summary of simple correlation coefficients of wood properties of sugarberry. Symbol in parentheses indicates whether "r" is positive or negative. Asterisk denotes statistical significance at the 1% level*

Wood Properties		All Data	Heights					Tree Number					
			5	15	25	35	45	1	2	3	4	5	6
Ring Width	Specific Gravity	(+)*	(+)*	(+)*	(-)	(+)	(+)	(-)	(+)*	(-)	(+)	(-)	(+)
Ring Width	Fiber Length	(-)*	(-)*	(-)*	(-)*	(-)	(-)	(-)	(-)*	(-)	(-)	(-)	(-)
Ring Width	Vessel Volume	(-)*	(-)*	(-)*	(-)*	(-)	(-)*	(-)	(-)*	(-)	(-)*	(-)	(-)*
Ring Width	Ray Volume	(-)	(-)	(-)	(+)	(+)	(+)	(-)	(-)	(-)	(+)	(-)	(+)
Ring Width	Fiber Volume	(+)*	(+)*	(+)*	(+)*	(+)*	(+)	(+)*	(+)*	(+)	(+)*	(+)	(+)*
Specific Gravity	Fiber Length	(-)*	(-)	(-)	(-)*	(-)	(+)	(-)	(-)	(-)	(-)	(-)	(-)
Specific Gravity	Vessel Volume	(-)*	(-)*	(-)*	(-)	(-)	(-)*	(-)	(-)*	(+)	(-)	(-)	(-)*
Specific Gravity	Ray Volume	(+)	(+)	(-)	(-)	(-)	(+)	(+)	(-)	(+)	(+)	(+)	(+)
Specific Gravity	Fiber Volume	(+)*	(+)*	(+)*	(+)*	(+)*	(+)	(+)	(+)*	(-)	(+)	(-)	(+)
Fiber Length	Vessel Volume	(+)*	(+)*	(+)*	(+)*	(+)*	(+)*	(+)*	(+)*	(+)*	(+)*	(+)*	(+)*
Fiber Length	Ray Volume	(+)	(+)	(+)	(+)	(+)	(+)	(-)	(+)	(+)*	(-)	(+)	(+)
Fiber Length	Fiber Volume	(-)*	(-)*	(-)*	(-)*	(-)*	(-)*	(-)*	(-)*	(-)*	(-)*	(-)*	(-)*
Vessel Volume	Ray Volume	(-)	(-)	(+)	(-)	(+)	(-)	(-)*	(+)	(-)	(-)	(+)	(-)
Vessel Volume	Fiber Volume	(-)*	(-)*	(-)*	(-)*	(-)*	(-)*	(-)*	(-)*	(-)*	(-)*	(-)*	(-)*
Ray Volume	Fiber Volume	(-)*	(-)*	(-)*	(-)*	(-)*	(-)	(-)	(-)*	(-)*	(-)	(-)*	(-)*

ring width and specific gravity and some have even reported a negative relationship. Recent reviewers and research reports show that rate of growth has little effect on specific gravity. It has been suggested by Goggans (1962) that an integral part, and perhaps the root of this controversy, is the existence and recognition of core wood. For example, the assumption that wide rings that occur near the pith cause low specific gravity wood (also normally found near the pith) is not necessarily correct; and certainly comparisons between trees where fast-growing core wood of one tree is compared with slow-growing mature wood of another tree are unrealistic (Goggans 1962).

Simple correlation coefficients for ring width and specific gravity failed to indicate a consistent relationship in any of the Delta hardwoods investigated. For sugarberry (Table 2), the large number of observations when all data were processed resulted in statistical significance of the small "r" value ($r = 0.16$). However, when the data were considered for individual heights, the relationship between specific gravity and ring width was significant at only two of the five heights studied. Likewise, the relationship was not strong within individual trees, and was, in fact, positive for some trees and negative for other trees.

Eccentricity in the sycamore study trees resulted in wedges of different length from the same sampling height. Such differences in radii may be associated with tension wood in long radii, but the different length radii definitely represent growth rate differences in tissue that is uniform in genetic constitution, height in the tree, age, and macro-environment. Hence, an evaluation of the specific gravity of long and short radii presents an opportunity to study the influence of growth rate on specific gravity with many of the variables that have confused this relationship held constant.

Differences in the specific gravity of long and short radii were small and not statistically significant. This lack of difference between specific gravity values of long and short radii from eccentric discs of sycamore, coupled with the lack of strong correlation between specific gravity and growth rate in the other Delta hardwoods studied, suggests that within a tree the influence of growth rate (within the range of normal growth rate) is less important than the influence of other factors on specific gravity.

Correlations of ring width and fiber length. In sugarberry, willow, and pecan, long fibers were associated with narrow rings. The relationship of these wood properties has been investigated by many authors, most of whom agree that fiber length is inversely related to radial growth rate (Amos et al. 1950; Bisset et al. 1951; de Zeeuw 1965). However, Kennedy (1957) reported that a fast rate of growth in black cottonwood does not have a deleterious effect on fiber length. Such differences were harmonized by Bailey (1920) with the statement that, "In many plants, the dimension and volume of tracheary cells are determined primarily by those of cambial initials, whereas in others they are largely due to changes which occur during the differentiations of the xylem."

Correlations of ring width and tissue types. Wide growth rings in willow, sugarberry, and pecan contained proportionately less vessel tissue than narrow growth rings. Such a negative relationship would be expected in a ring-porous species like sugarberry, because springwood growth zones occupy proportionally more of the annual growth area during slow-growth periods than during fast-growth periods. This, however, will not suffice as an entirely adequate generalized explanation for the growth rate—vessel volume correlation; for similar correlations were found for pecan (a semi-ring-porous species) and black willow (a diffuse-porous species), and have been reported for yellow poplar (Taylor 1968b). The relationship of growth rate and vessel volume in one pecan tree is illustrated graphically in Fig. 14.

In most cases, the decreased vessel volume of wide rings was compensated for by an increase in the volume of fibrous tissue, with little change in the proportion of ray parenchyma.

Correlations of specific gravity and tissue types. High specific gravity was generally associated with an increase in fiber volume and a decrease in vessel volume. The relationship between specific gravity and ray volume was not strong, but it should be noted that increased ray volume does not detract from specific gravity. Research with broad-ray species has indicated that increased ray volume may result in increased specific gravity (Taylor 1969b).

Correlations of fiber length and tissue types. These variables were significantly correlated only in sugarberry where fiber length was greatest in tissues with large vessel volume and low fiber volume. This is possibly the result of the influence of age of the cambium on tissue type and fiber length coupled with the fact that age is negatively correlated with ring width.

Correlations of tissue types. Interrelationships among the proportional volume of vessels, fibers, and ray parenchyma were mostly negative and correlation coefficients were frequently significant. These relationships are, however, of no practical significance, since an increase in the proportion of one tissue type must, obviously, be associated with a decrease in the amount of one or more other tissue types.

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