VESSEL AREA STUDIES IN BLACK WALNUT (*JUGLANS NIGRA* L.)

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ABSTRACT

This study examined factors that influence variation in vessel lumen area (a measure of wood texture) in black walnut (*Juglans nigra* L.) trees. The effects of management type (plantation and naturally grown trees) and location within the tree (both longitudinally and radially) on earlywood vessel lumen area, latewood vessel lumen area, and total growth ring vessel lumen area were examined. In general, faster grown, managed, plantation-grown trees had a higher earlywood vessel lumen area than slower grown, unmanaged, naturally grown trees; but naturally grown trees had a greater total vessel lumen area per growth ring. No correlation was observed between rate of growth and earlywood vessel lumen area, but there was a correlation between rate of growth and area of latewood vessel lumens and the area of vessel lumens within growth rings. Significant differences were observed longitudinally within trees; that is, samples from disks removed from the 8½-foot level had a higher vessel lumen area (in both earlywood and total vessels) than samples from disks removed from the base of the tree. In addition, with increasing distance from the pith, there was an increase in vessel lumen area within the earlywood and an increase in vessel lumen area within the entire growth ring. Results of this study suggest that management activities can influence the area of vessel lumens within growth rings of black walnut through an effect on growth rate of the trees. However, within-tree variations in these properties occur also and these must be considered.

Keywords: Wood properties, wood quality, texture, fine hardwoods.

INTRODUCTION

Texture and heartwood color are the two most important wood quality properties of hardwoods used for veneer (Kesner 1986). Vessel lumen area contributes directly to wood texture and is, therefore, an important wood quality feature of black walnut and other fine hardwoods. Vessel lumen area is influenced by the size (radial and tangential diameter) of the vessels and the number of vessels per unit area in relation to the rest of the cells in the growth ring.

In general, past studies have shown an increase in the radial and tangential vessel diameters with increasing distance from the pith (Dadswell 1958; Desch 1932; McKimm and Ilic 1987). Along with this, however, is a decrease in the number of vessels with increasing distance from the pith (Dadswell 1958; McKimm and Ilic 1987). Studies on vessel lumen area, however, have produced somewhat inconsistent results. Researchers have observed a general trend of increasing vessel lumen area with increasing distance from the

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pith, but this trend has not held true for all species (Desch 1932; Taylor and Wooten 1973).

Past studies on black walnut wood properties have examined specific gravity (Boyce et al. 1970; Paul 1963) and fiber length (Mell 1910). Panshin and deZeeuw (1980) described variation of vessel element length and diameter within growth rings. Research examining the relationships between vessel lumen areas and growth rate in black walnut has produced somewhat mixed results. Hiller et al. (1972) found no significant differences in percentage vessel lumen area between good and poor site classes of trees or between fast and slow grown trees. However, Boyce et al. (1970) and Maeglin et al. (1977) reported an inverse relationship between vessel lumen area and growth rate.

Because of these conflicting reports and because vessel lumen area is an important criterion of wood quality, we chose to examine variation in vessel lumen area of 10 black walnut trees grown in southern Illinois. Trees were selected, based primarily on similar size, from a managed plantation area and from an adjacent unmanaged woods-grown area. They were sampled and analyzed to describe variation in vessel lumen area as it is influenced by growth rate (which is influenced by management method), and the variation between and within trees.

MATERIALS AND METHODS

Five plantation-grown and five naturally grown black walnut trees were harvested from experimental plots on the Shawnee National Forest in southern Illinois. Trees were chosen, initially, because of their similar size. The plantation-grown trees contained 22 growth rings at the stump; the naturally grown trees contained an average of 30 growth rings at the stump (range 24 to 33). In a previous study, Phelps and Chen (1989) described tree age, tree height, log grade, lumber quality (shrinkage, checks, and grades), and specific gravity of the same trees used in the present study. For the present study, 2-inch-thick disks from the top (8½-foot level) and the bottom of the first log were removed. A radial section (pith to bark, approximately ⅜ inch wide) was removed from each disk. This section was divided into 1-inch sample blocks radially, which were trimmed to a 1-inch length. All blocks were prepared for sectioning by boiling in water for 2 hours.

Cross sections, 20 microns thick, were sliced from each sample block and were stained using a safranin-fast green staining procedure (Sass 1958). The procedure was slightly modified to eliminate xylene during the dehydration schedule by using a mounting resin (Euparal) that is miscible with ethyl alcohol. Adequate staining was obtained after 5 minutes in a 1% solution of aqueous safranin, followed by 30 seconds in 1% fast green in 95% ethyl alcohol.

Vessel lumen area was measured using a Delta-T Area Meter system attached to a Carl Zeiss Universal microscope that had a rotating stage. The microscope had a one-tenth-mm scale, which enabled accurate determinations of the width of each growth ring. Preliminary microscopic observations of the microtomed cross sections of wood led us to make the following assumptions: earlywood vessel lumen areas could be described as being those in the first 1.41 mm (radially) of each growth ring; latewood vessel lumen areas could then be assumed to be those in the remainder of the growth ring; and total vessel lumen area for each growth ring could be obtained by averaging earlywood vessel lumen area measurements with the corresponding latewood measurements for that growth ring.

The sensitivity of the area meter was calibrated as follows: A grid was superimposed on the monitor viewing screen. Lumen area was estimated by counting the number of crossed points that fell upon vessel lumens in the area being viewed. This number was divided by the total number of crossed points to estimate the percentage vessel lumen area occupied by the sample area depicted on the screen. The resulting estimate was used to calibrate the digital readout of the area meter. This procedure was done once for each earlywood and once for each latewood region in each microtomed cross section. After this calibration, another

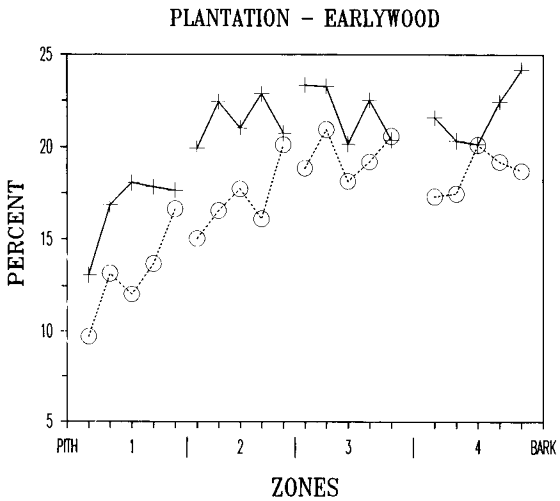

FIG. 1. Percent earlywood vessel lumens in growth rings, within zones and at two sample heights in plantation-grown black walnut trees. Top disk samples are designated by +, bottom disk by the O. Zone 1 includes growth rings 1 to 5, zone 2 includes growth rings 6 to 10, zone 3 includes growth rings 11 to 15, and zone 4 includes the 5 outermost growth rings.

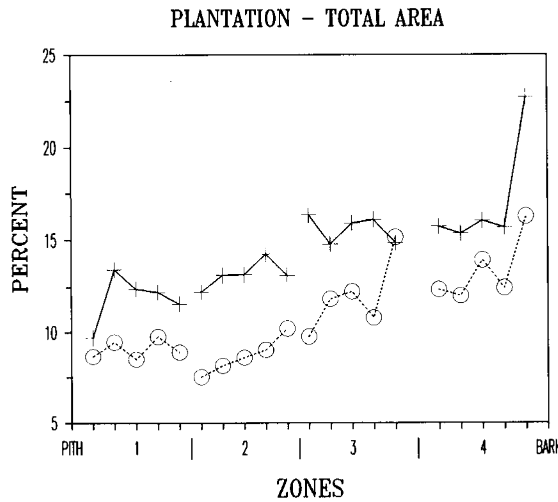

FIG. 2. Percent total vessel lumen area in growth rings, within zones and at two sample heights in plantation-grown black walnut trees. Top disk samples are designated by +, bottom disk by the O. Zone 1 includes growth rings 1 to 5, zone 2 includes growth rings 6 to 10, zone 3 includes growth rings 11 to 15, and zone 4 includes the 5 outermost growth rings.

earlywood or latewood region from the same microtomed wood section was moved into position on the viewing screen, and vessel lumen area was automatically tabulated by the readout on the meter. The procedure was continued until all areas of the earlywood or latewood regions were measured. The microtomed sections were large enough to obtain two to three measurements for each earlywood area on each microtomed wood section. The number of measurements that were obtained for latewood vessel lumen areas was dependent on the radial width of the growth ring. Average vessel lumen areas for each growth ring were obtained by accumulating the earlywood and latewood vessel lumen area readings and dividing by the number accumulated.

Before statistical analysis, we plotted the data to examine radial and longitudinal trends within the plantation-grown and the naturally grown trees. Preliminary graphs of the data suggested that our evaluations could be reduced to an examination of the first 15 years of growth (to include the juvenile region of growth) and the outermost 5 years of growth (to include the mature wood region of growth). These preliminary graphs also suggested that the growth rings could be further grouped into zones with five growth rings in each zone. As one would expect, there was considerable variation in the widths of growth rings. Several of the narrower growth rings had no latewood in them at all. Because of this, data were expressed as earlywood vessel lumen area or an average of the total vessel lumen area within each growth ring.

We performed statistical analyses to determine if there were significant differences in vessel lumen area between plantation-grown and naturally grown trees, among trees, between locations (disks) within trees, and between the juvenile wood and mature wood zones within trees. We were also interested in determining if vessel lumen area or the duration of juvenile wood period (as defined by vessel lumen area) were influenced by growth rate. Statistical analyses of the data were conducted using a balanced, N-way Analysis of Variance, and Scheffe's Test for Contrasts (Steele and Torrie 1980). Pearson's Correla-

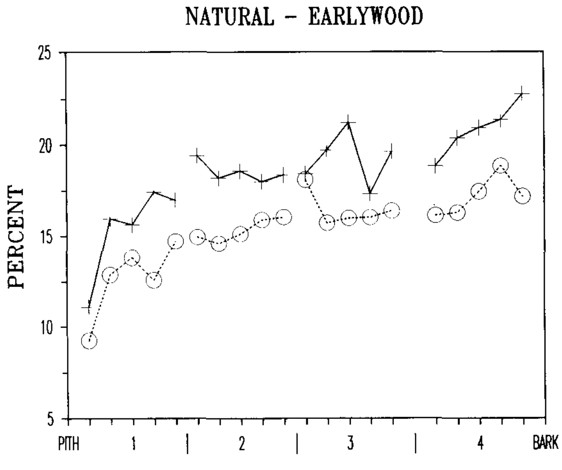

FIG. 3. Percent earlywood vessel lumens in growth rings, within zones and at two sample heights in naturally grown black walnut trees. Top disk samples are designated by +, bottom disk by the O. Zone 1 includes growth rings 1 to 5, zone 2 includes growth rings 6 to 10, zone 3 includes growth rings 11 to 15, and zone 4 includes the 5 outermost growth rings.

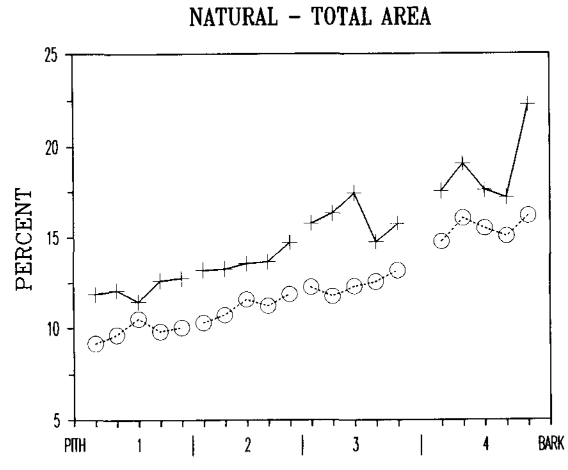

FIG. 4. Percent total vessel lumen area in growth rings, within zones and at two sample heights in naturally grown black walnut trees. Top disk samples are designated by +, bottom disk by the O. Zone 1 includes growth rings 1 to 5, zone 2 includes growth rings 6 to 10, zone 3 includes growth rings 11 to 15, and zone 4 includes the 5 outermost growth rings.

tion analysis was also done to examine interrelationships between distance from the pith, earlywood vessel lumen area, latewood vessel lumen area, growth ring vessel lumen area, and growth ring width. Scheffe's test is considered conservative in that the test must have a large critical value for any contrast to be accepted as valid. Because of the low number of sample trees, particularly in the comparisons between management types and positions, a conservative test was deemed appropriate.

RESULTS AND DISCUSSION

Figures 1 through 4 show average values for earlywood vessel lumen areas and total ring vessel lumen area, for plantation-grown (n = 5) and naturally grown trees (n = 5), and for the two heights sampled (+ = top disk from 8½ feet and O = bottom disk from the stump level of the trees). Plotting of the data suggested that there were differences related to position within the sample trees, and to a lesser extent, differences in properties between plantation-grown and naturally grown trees.

Overall vessel lumen area variation in the sample trees

Plantation-grown trees had a significantly higher percentage of earlywood vessel lumen areas, a significantly lower percentage of total vessel lumen areas within the growth ring, and significantly wider growth rings than naturally grown trees (Table 1). Top disks contained a significantly higher percentage of earlywood and total vessel lumen areas than the bottom disks and wider growth rings. Although growth rings were wider, the difference in growth rings between heights was not as great as between the plantation-grown and naturally grown trees.

Samples from various radial zones also showed some statistically significant differences in earlywood vessel lumen areas, total vessel lumen areas, and growth rates in the zones closest to the pith (Table 1). The earlywood vessel lumen areas in zone one (the five growth rings nearest the pith) and zone two (growth rings six to ten from the pith) were significantly different from each other and were different (less than) from zones three and four.

Earlywood vessel lumen area was not different between zone three (growth rings 11 to 15 from the pith) and zone four (the outermost five growth rings in the sample disk). There were also significant differences among zones in total percentage vessel lumen area; the outermost zones had a higher percentage of total vessel lumen area than the innermost zones (Table 1). In addition, significant differences in growth rates were noted; the outermost zone had the slowest growth rate, and zone two (growth rings 5 through 11) had the fastest growth rate.

However, one must be careful to recognize significant variations (both longitudinally and radially) within individual trees. If juvenile wood (the zone in the center of the tree that has rapid changes in characteristics) can be described and defined by changes in the percentage of earlywood vessel lumen areas, then the transition from juvenile wood to mature wood occurred after the tenth year from the pith, regardless of growth rate.

TABLE 1. *Means for wood properties where the responses were measured over all levels. Means followed by the same letter are not statistically significantly different at the 0.05 level.*

Source	Earlywood % vessel area	Total % vessel area	Growth ring width (mm)
Plantation	18.8	12.7	6.8
Natural	16.9	13.6	4.5
Top disk	19.5	14.8	5.4
Bottom disk	16.2	11.5	5.9
Zone			
4	19.6 A	16.2	3.7
3	19.3 A	14.0	5.4 A
2	18.1	11.7	8.0
1	14.5	10.7	5.4 A

Vessel lumen area variation in plantation-grown trees

Statistical analyses on the wood properties from plantation-grown trees (Table 2) were conducted to describe, in more detail, these differences in wood properties between trees and within trees (zones or heights). Significant differences between and within plantation-grown trees were observed, but there was also much uniformity (e.g., lack of statistically significant differences), particularly in the top disk. The data agree with those in Table 1. There was an increase in earlywood and total vessel lumen area from the pith to the bark in the disks from the plantation-grown trees. The average width of the growth rings varied depending on height of disk within the tree.

Vessel lumen area variation within naturally grown trees

Statistical analyses were also conducted on the wood properties from naturally grown trees (Table 3). The tests on properties of the naturally grown trees showed more variability between trees and within trees (Table 3) than the data from the plantation-grown trees. However, similar differences were noted between trees and between zones within trees as were observed in the plantation-grown trees.

Observations and comparisons with previous studies

The data from Tables 1 through 3 strongly suggest that there were differences between management types (plantation-grown and naturally grown), that differences between trees could be observed in these properties, and that differences in earlywood vessel lumen area could be observed depending on distance from the pith.

Desch (1932) cited earlier work by Clarke and Hartig, which showed an increase in earlywood vessel percentage and a decrease in percentage of fibers with distance from the pith. Desch (1932), however, observed some inconsistencies in this relationship. For example, he observed an increase in vessel area percentage with increasing distance from the pith in Rhodesian teak (*Baikiaea plurijuga* Harms.), but in birch (*Betula pubescens* Ehrh.) he observed a decrease. More recently, Taylor and Wooten (1973) studied five southern hardwoods and found a general increase in vessel area with distance from the pith in black willow (*Salix nigra* Marsh.), willow oak (*Quercus phellos* L.), sycamore (*Platanus occidentalis* L.),

TABLE 2. *Means for individual wood properties in plantation-grown black walnut trees and tests of differences between main effects. Means followed by the same letter are not significantly different at the 0.05 level.*

Bottom disk					
Earlywood % vessel area		Total % vessel area		Growth ring width (mm)	
Tree no.	Mean (n = 20)	Tree no.	Mean (n = 20)	Tree no.	Mean (n = 20)
5	18.6 A	2	12.2 A	5	8.7 A
2	17.8 AB	3	11.4 AB	1	6.9 AB
3	17.3 AB	5	10.4 BC	3	6.9 AB
4	16.2 AB	4	10.2 BC	4	6.8 AB
1	15.5 B	1	9.7 C	2	6.6 B
Zone	Mean (n = 25)	Zone	Mean (n = 25)	Zone	Mean (n = 25)
3	19.5 A	4	13.4	2	10.8
4	18.6 AB	3	11.9	3	7.5
2	17.1 B	1	9.1 A	4	5.6 A
1	13.1	2	8.7 A	1	4.8 A
Top disk					
Earlywood % vessel area		Total % vessel area		Growth ring width (mm)	
Tree no.	Mean (n = 20)	Tree no.	Mean (n = 20)	Tree no.	Mean (n = 20)
4	21.3 A	2	16.6	5	7.3 A
2	20.7 A	4	14.6 A	4	7.1 A
3	20.4 A	5	14.0 A	3	6.0 A
5	20.2 A	3	13.8 A	1	5.7 A
1	19.8 A	1	13.7 A	2	5.6 A
Zone	Mean (n = 25)	Zone	Mean (n = 25)	Zone	Mean (n = 25)
3	21.9 A	4	17.1	2	8.5
4	21.7 A	3	15.6	1	6.6 A
2	21.4 A	2	13.2 A	3	5.6 AB
1	16.7	1	12.3 A	4	4.7 B

and sugarberry (*Celtis laevigata* Willd.), but pecan (*Carya illinoensis* (Wangenh.) K. Koch) did not conform to this general pattern of change with increasing distance from the pith. Our observations, as shown in Figs. 1 to 4, agree with the general trends of increasing earlywood and total vessel areas within growth rings with increasing distance from the pith.

Hiller et al. (1972) reported average vessel lumen area of 16.5% for Indiana-grown trees and 19.4% for Missouri-grown black walnut trees. Their samples were taken from bolts from the 8- to 13-foot level in the trees and, thus, are similar to our "top disk" samples. Our vessel lumen area values from the mature wood zone are quite similar to those described by Hiller et al. (1972). Boyce et al. (1970) reported an average vessel lumen area of 26% for five black walnut trees. In Boyce et al.'s (1970) study, vessel lumen area measurements were taken from samples throughout the merchantable bole of 75- to 120-year-old, woods-grown trees, which had a growth rate of 9 to 11 rings per inch at dbh.

Correlation analyses

Correlations presented in Table 4 indicate that all factors were correlated with one another except percentage earlywood vessel lumen areas and growth ring width. Growth ring width and latewood vessel lumen area and total vessel lumen areas were negatively correlated. Apparently, semi-ring porous black walnut behaves similarly to ring porous species, i.e., as the rate of growth increases, production of fibers in the latewood region increases. Boyce et al. (1970) found that as growth rate increased, there was an increase in fiber area, a

TABLE 3. *Means for individual wood properties in naturally grown black walnut trees and tests of differences between main effects. Means followed by the same letter are not significantly different at the 0.05 level.*

Bottom disk					
Earlywood % vessel area		Total % vessel area		Growth ring width (mm)	
Tree no.	Mean (n = 20)	Tree no.	Mean (n = 20)	Tree no.	Mean (n = 20)
4	17.9 A	4	14.5 A	5	5.5 A
1	17.9 A	1	13.2 A	4	5.1 A
2	14.3 B	5	11.6 B	3	4.5 AB
5	13.7 B	3	11.2 B	1	4.5 AB
3	12.9 B	2	10.5 B	2	3.4 B
Zone	Mean (n = 25)	Zone	Mean (n = 25)	Zone	Mean (n = 25)
4	17.1 A	4	15.4	2	6.6
3	16.4 A	3	12.4	1	4.8 A
2	15.3 A	2	11.1	3	4.7 A
1	12.6	1	9.8	4	2.2
Top disk					
Earlywood % vessel area		Total % vessel area		Growth ring width (mm)	
Tree no.	Mean (n = 20)	Tree no.	Mean (n = 20)	Tree no.	Mean (n = 20)
1	20.9 A	1	16.8 A	5	5.3 A
4	20.5 A	4	15.8 AB	4	4.9 A
5	18.6 AB	5	15.2 AB	1	4.1 A
2	17.4 BC	2	14.1 BC	2	4.0 A
3	15.1 C	3	13.2 C	3	3.9 A
Zone	Mean (n = 25)	Zone	Mean (n = 25)	Zone	Mean (n = 25)
4	20.8 A	4	18.7	2	6.2 A
3	190.3 AB	3	15.9	1	5.5 A
2	18.5 B	2	13.7	3	3.9
1	15.4	1	11.7	4	2.1

decrease in vessel lumen size, and a decrease in the number of vessels. They reported correlations of −0.31 between width of growth rings and distance from the pith, and −0.42 for width of the growth rings and vessel lumen area. These values correspond to correlations of −0.29 and −0.47, respectively, of the present study. In addition, Boyce et al. (1970) reported a correlation of 0.35 between vessel lumen area and distance from the pith. We found a correlation of 0.60 for this same relationship and positive relationships between distance from the pith and percentage of earlywood and latewood vessel lumens. Maeglin et al. (1977) reported that the anatomical differences observed in their study were mostly related to growth rate in black walnut. After reviewing the literature on wood properties of improved trees grown under intensive management, Bendtsen (1978) concluded that wood properties (specific gravity and fiber characteristics) were influenced more by number of rings from

TABLE 4. *Pearson's correlation matrix for 10 black walnut trees.*

	Earlywood vessel %	Latewood vessel %	Growth ring vessel %	Growth ring width
Distance from pith	0.46	0.45	0.60	−0.29
Earlywood vessel %		0.50	0.68	0.09[ns]
Latewood vessel %			0.92	−0.39
Growth ring vessel %				−0.47

[ns] Indicates that the correlation is not significantly different from 0, alpha = 0.05.

the pith (or distance of the wood from tree center) than by rate of growth of the wood. Results of analyses in the present study indicate that distance of the wood from tree center does indeed influence percentage of vessel lumens, primarily in the earlywood. However, growth rate also has an influence. As growth rate increases, the percentage of the growth ring that is latewood increases, and since latewood has fewer, smaller vessels, this results in lower percentages of total vessel areas per growth ring. Distance from tree center, the longitudinal position of the sample within the tree, and the growth rate all influence vessel lumen area percentages.

CONCLUSIONS

In summary, managed, faster grown plantation trees had a higher percentage of earlywood vessel lumens, but a lower percentage of vessel lumens within the total growth ring than unmanaged trees. In addition, radial and longitudinal variation in vessel lumen areas was observed as well as variation due to growth rate on percentage of latewood vessel lumens. There was more uniformity in earlywood vessel lumen areas between plantation grown trees, primarily in the samples taken from the top disk. Earlywood vessel lumen areas were influenced more by distance from the pith than by growth rate. Management of black walnut causes wider growth rings, which have wider latewood zones. Wider latewood zones reduce the vessel area of the latewood and the total vessel area within the growth ring. The practical effect of increased growth rate is a reduction in total vessel lumen area, which causes a poorer texture of the wood. During management of black walnut, one has to realize that a faster growth rate will result in poorer texture quality of the wood. However, management will also favor a more uniform wood texture.

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