GROWTH-QUALITY EVALUATION OF BLACK WALNUT WOOD. PART II—COLOR ANALYSES OF VENEER PRODUCED ON DIFFERENT SITES[1]

John E. Phelps
Forest Products Technologist
Forestry Sciences Laboratory, P.O. Box 898
Rhinelander, WI 54501

E. A. McGinnes, Jr., H. E. Garrett, and G. S. Cox
Professors
School of Forestry, Fisheries and Wildlife, 1-31 Agriculture Building
University of Missouri, Columbia, MO 65211

(Received 6 June 1982)

ABSTRACT

Heartwood color is an important wood quality parameter in the grading of black walnut veneer. One of the primary factors that causes a reduction in veneer grade is variability in heartwood color. This variability may be in the form of streaked heartwood or in coloration not of a uniform light chocolate brown nature. Black walnut trees from four distinctly different sites were selected to describe wood color of commercially prepared veneer sheets, using standard color measurement techniques, so that within-tree, between-tree, and between-site variations could be determined. Selected logs were sliced into veneer by a commercial process and the veneer was graded according to industrial standards. Reflectance data were obtained from selected veneer samples and these data were transformed into standard color parameters. Wide ranges in luminance and purity parameters were obtained. However, only the differences in luminance were detectable upon visual examination. This suggests that variability in luminance (i.e., darkness or lightness) is the primary cause of heartwood color variability. These analyses revealed statistically significant within-site differences in heartwood luminance, but within-tree differences were also observed. Between-site differences were considered less important than within-site differences.

Keywords: Spectrophotometry, wood color, *Juglans nigra* L., veneer.

INTRODUCTION

Black walnut (*Juglans nigra* L.) has several characteristics that contribute to its reputation as a fine hardwood species. Although its good physical and machining properties are important, walnut's appeal is primarily aesthetic. This means that figure and color are important wood quality characteristics.

Characteristics that detract from the value of walnut veneer include nonuniform color and grain (except feather grain) in the veneer log, shorter log lengths, large

---

[1] This work was conducted while the senior author was a Research Associate at the University of Missouri and is part of his Ph.D. dissertation. The authors would like to extend their appreciation to the North Central Forest Experiment Station for contributing some of the sample material for this study and to Mr. Jim Burroughs for his assistance in computer and statistical matters. Use of trade names in this manuscript does not constitute endorsement by the USDA Forest Service or the University of Missouri. Current address of John Phelps is University of Missouri.

Wood and Fiber Science, 15(2), 1983, pp. 177–185
© 1983 by the Society of Wood Science and Technology

amounts of sapwood, and the presence of rot and excessive knots. Unfortunately, these defects are much too common.

Nonuniform wood color, whether within-tree, between-tree, or between-site, is one area where more research is needed. It is the purpose of this paper to describe such variations, using standard analytic techniques, in heartwood color of commercially prepared veneer from logs of known site history.

MATERIALS AND METHODS

The materials for this study were obtained from trees used in other studies within the University of Missouri, School of Forestry, Fisheries and Wildlife's multidisciplinary effort on black walnut research (Szopa et al. 1980; Yen et al. 1978). Eight black walnut trees were harvested from each of three sites in the state of Missouri. The indices of these sites (S.I.) were 66, 80, and 81 for black walnut at age 50. Two sites, the Duffy (S.I. = 60) and Fox (S.I. = 80) sites, were located near Stockton, Missouri, on stony soil. The third site, the DuPont site (S.I. = 81), was located near Ashburn, Missouri, on deep, river bottom soil. Even though the Fox and DuPont sites had similar site indices, there were some distinct differences in soil properties. More complete descriptions of the sites are given in Yen et al. (1978) and Szopa et al. (1980).

Five logs were also harvested from Carbondale, Illinois. Although the soil around the trees was not subjected to the same analyses as the Missouri trees (root mapping, physical and chemical analyses), color properties of the logs were characterized because of past management treatments on the site.

Butt logs, 1.5 to 1.8 meters (5 to 6 feet) long, from each of the 29 trees were sliced into veneer according to an industrial schedule. A slab was removed from one side of the log in a sawmill to facilitate handling by the veneer slicing machine. The logs were placed into a hot water bath for 2 to 3 days, removed, debarked, and the flat side of the log was placed against the carriage of the veneer cutting machine. Veneer sheets were then sliced off the log by an up-and-down motion of the carriage. The veneer knife advanced into the log at set intervals (ca. 1 mm or $^{1}/_{30}$ inch), and veneer sheets were carried via a belt conveyor system to where they were manually stacked into a flitch (a stack of sliced veneer sheets from one log). Walnut heartwood has a greenish color when first sliced, and if the veneer is dried immediately after slicing, the greenish color will be set in. A 24-hour period is required between the slicing and drying to allow the color to change to the desired brown color. After this setting period, the sheets were dried, one by one, in a conveyor drier. At the end of the dryer, three sheets were removed at one-fourth intervals through the flitch for grading purposes. Each sheet was tagged with an identifying number that denoted the sample tree and the location of the sheet within the flitch.

After the grader evaluated the veneer from all trees, five flitches of veneer were selected by visual means to represent good quality veneer (one flitch) and poorer qualities of veneer (four flitches). Flitches were selected that exhibited color features both beneficial (uniform light chocolate brown color) and detrimental (nonuniform sheet color, streaking) to the grading of the veneer and were not selected with regard to site (site index, soil properties, etc.). These preliminary visual evaluations of the 29 trees suggested that as much within-site variation occurred as between-site variation (e.g., the good quality and two poorer quality trees came

TABLE 1. *Soil chemical and physical properties around the individual trees used in this study averaged for the 0- to 120-cm depth.*

Tree*	Soil depth (cm)	Depth to mottling (cm)	Available water (cm)	Bulk density (g/cc)	Stone content (% vol)	Moisture @ 15 bars (% vol)	Moisture @ .33 bars (% vol)	Total porosity (% vol @ 15 bars)	Air porosity (% vol @ .33 bars)	Organic matter (% o.d. wt.)	Silt plus clay (%)
1	149	85	11.75	1.38	13	18	28	48	20	1.2	76
2	250	61	19.85	1.45	5	24	41	46	5	1.9	91
3	250	91	26.40	1.44	0	29	51	44	0	2.9	98
4	250	86	17.40	1.42	0	24	38	46	8	2.9	95

Tree*	pH	Base saturation (%)	Cation exchange capacity (meq/100 g)	N (ppm)	P (ppm)	K (ppm)	Ca (meq/100 g)	Mg (meq/100 g)	Zn (ppm)	Mn (ppm)	Fe (ppm)	Cu (ppm)	Mn/Fe ratio	Ca/Mg ratio	P/Zn ratio
1	5.6	80	8.0	750	12	83	4.2	1.9	0.2	17	12	0.6	1.4	2.2	60
2	7.3	100	14.2	1200	52	120	12.6	1.5	1.7	25	15	2.4	1.6	8.4	31
3	7.5	100	15.1	1850	73	131	12.3	2.2	1.9	27	19	1.8	1.4	5.6	38
4	7.7	100	15.8	1850	76	128	12.5	2.9	2.0	14	20	1.8	0.7	4.3	38

* Tree number 1 came from the Duffy site; trees 2, 3, and 4 came from the DuPont site.

from within the DuPont site). Therefore, we chose to concentrate on color variations within and between trees. A fourth tree (of poorer quality) came from the Carbondale, Illinois, site and another poor quality tree came from the Duffy site.

For our spectrophotometric color analyses, we removed veneer sheets immediately adjacent to the three sheets evaluated at the industrial plant. A small strip, oriented radially to the sheet, was selected from each sheet to represent the color properties of that sheet. The strips were subdivided into six to eleven sample positions depending on the radial width of the sheet. Each sample was given an identifying number that indicated the tree, the sheet, and the sample position within the sheet. Percent reflectance data were collected at 10 nanometer (nm) intervals over the visible light spectrum (400 to 700 nm) by using a spectrophotometer. Measurements were done on longitudinally oriented, "as sliced," samples at ambient temperature and ambient relative humidity. A barium sulphate (white) disk was used to standardize the reflectance readings.

The X, Y, Z tristimulus values and the x and y chromaticity values were computed from the reflectance data. The tristimulus values were derived using the transformation tables of Wright (1969). The formulae and tables of Judd (1933) were used to compute dominant wavelength (hue). The formulae of Wyszecki and Stiles (1967) were used to compute percentage purity (saturation). Percentage luminance (brightness or lightness) was derived directly from the Y tristimulus value. The color terms represent quantitative descriptions of the color of an object and are meant to describe that color as it would appear to a standard observer. There are criteria implied in this type of quantitative description. First, the standard observer is actually an averaged description of the color perceived by many people who have normal color vision. Secondly, the color of an object also depends on the type of illuminating source, i.e., colors appear different under tungsten, fluorescent, or sun light. Therefore, three standard illuminating sources are used for these analyses: type "A" (equivalent to a tungsten lamp operating at a color temperature of 2848° Kelvin), type "B" (equivalent to noon daylight with a color temperature of 4800° Kelvin), and type "C" (equivalent to averaged daylight with

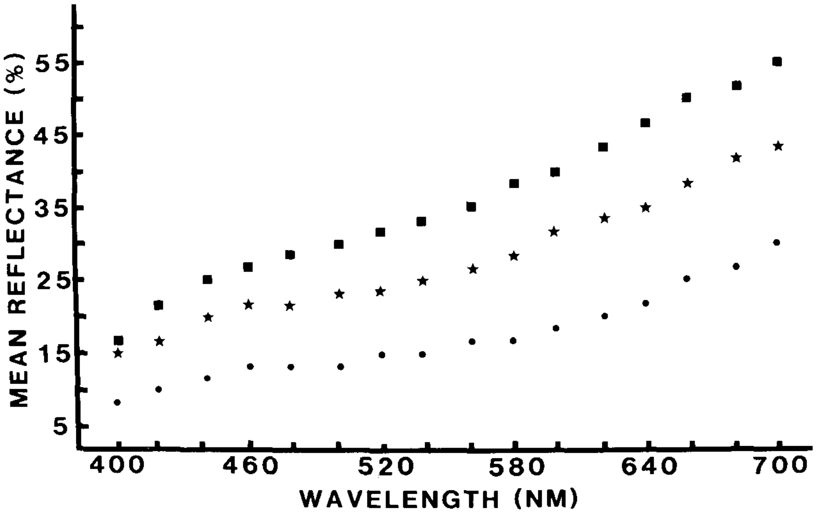

FIG. 1. Mean reflectance values for sapwood veneer (■), visually light heartwood veneer (★), and visually dark heartwood veneer (●). Reflectance values at each wavelength in each curve are significantly different from the other values in the other curves at the 0.05 level (L.S.D. test).

a color temperature of 6500° Kelvin). Types "A" and "C" have been commonly used in wood color research and were used in this study. These criteria are considered in the formulation of the transformation tables mentioned above.

A complete description of the methods used to derive physical and chemical properties of the soil surrounding each tree is given by Yen et al. (1978). The chemical data were obtained through extraction, except for nitrogen, which is expressed as total nitrogen. These analyses were done by a commercial laboratory. These physical and chemical data (Table 1) are given so that the reader may have a more thorough understanding of the areas from which the trees were taken.

RESULTS AND DISCUSSION

Mean reflectance values for walnut veneer samples selected to represent visually detectable extremes in wood color are given in Fig. 1. These data not only indicate the smooth, slightly sigmoid curves obtained from the spectrophotometric readings but also illustrate the variation that occurred within the sampling population. For convenience, the data are expressed in 20-nm intervals in Fig. 1. The smoothness of wood color curves suggests that wider (e.g., 30-nm) intervals could be used (i.e., wood reflectance has no abrupt peaks). This phenomenon has been observed in other studies (Brauner and Loos 1968; Loos and Coppock 1964; Moslemi 1967). Each reflectance reading at each wavelength in a curve was significantly different from the corresponding reflectance reading in the other curves (least significant difference test, alpha = 0.05). It was apparent then that much variation existed, not only between sapwood and heartwood, but also within the heartwood sampling population and that those differences observed with the unaided eye could be quantified using spectrophotometric techniques.

The reflectance values for the darker heartwood samples and for the lighter heartwood samples were comparable with values previously reported for walnut

TABLE 2. *Color descriptions of 90 heartwood and 30 sapwood veneer samples.*

Source "A" illuminant	Luminance (%)	Dominant wavelength (nm)	Purity (%)
Heartwood			
average	22.051	592.9	27.6
range	16.988–29.539	591–595	23.1–34.0
Sapwood			
average	37.187	590.7	30.1
range	28.503–47.818	590–592	23.0–34.0

Source "C" illuminant	Luminance (%)	Dominant wavelength (nm)	Purity (%)
Heartwood			
average	21.025	584.5	18.8
range	16.205–28.129	582.2–586.2	15.4–23.7
Sapwood			
average	35.488	582.3	21.0
range	26.998–46.183	581.1–583.7	15.9–23.2

heartwood veneer (Moslemi 1967). The reflectance readings described by Moslemi (1967) also depicted the same general shape of the curves (i.e., greater reflectance in the orange-red region of the visible spectrum) and the same general variations within the sampling population in reflectance properties. Comparisons of our data with those of Moslemi (1967) lend credence to the reproducibility of such measurements and thus indicate the reliability of the method.

The reflectance values depicted for the sapwood samples illustrate their higher reflectivity throughout the visible spectrum. Because these reflectance readings were standardized to a white substance, it follows that the lighter in color the material being examined, the higher would be the reflectance readings. Although the sapwood samples appear "whiter" than the heartwood samples upon visual examination, they have similar reflectance curves with regard to overall shape and slope. A possible reason for the similarity of these curves may be that the higher curve more nearly approximates the reflectivity of basic wood substances (cellulose, hemicelluloses, and lignin) and the lower curves represent the addition of varying degrees of other coloring compounds.

The mean color values and their ranges for heartwood and sapwood samples are given in Table 2. This table presents data obtained when using values representing source "A" and source "C" as the standard illuminants. These data compare favorably with those values previously reported by Moslemi (1967) and Nelson et al. (1969) for values obtained using the source "A" illuminant weighting functions. Moslemi (1967) reported average luminance values of 17.7%, average dominant wavelength values of 595.4 nm, and average purity values of 27.7% for 20 heartwood veneer samples. Luminance and dominant wavelength had to be computed from his chromaticity coordinates. Nelson et al. (1969) reported average luminance of 25.3%, average dominant wavelength of 594.9 nm, and average purity of 31.0% for 512 heartwood samples. Previous authors (Beckwith

TABLE 3. *Mean heartwood and sapwood luminance (and standard deviations) for the five trees evaluated in this study—source "A" illuminant.*

Tree number	Heartwood n[1]	Luminance (%)
1 (poor)	16	20.429^{a}[2] ± 2.163
2 (poor)	17	20.478^{a} ± 1.927
3 (poor)	13	20.707^{a} ± 1.510
4 (poor)	22	21.527^{a} ± 3.294
5 (good)	22	25.765^{a} ± 1.941

Tree number	Sapwood n[1]	Luminance (%)
1 (poor)	6	34.380^{a} ± 5.355
3 (poor)	6	35.607^{a} ± 2.726
4 (poor)	6	$37.134^{a,b}$ ± 3.033
2 (poor)	6	$37.912^{a,b}$ ± 1.456
5 (good)	6	40.905^{b} ± 4.430

[1] n = Number of observations.

[2] Values followed by the same superscript are not significantly different at the 0.05 level using the L.S.D. test. Similar trends were observed using the source "C" weighting functions.

1974; Loos and Coppock 1964; Moslemi 1967) have obtained similar readings to those described above for reflectance readings weighted with the illuminant "C" values.

The sapwood color parameters were approximately 15% higher in luminance, 2 nm lower in dominant wavelength, and approximately 3% higher in purity than the heartwood samples, no matter which of the two standard illuminant weighting factors was used.

Results obtained using the "A" illuminant factors were somewhat redder (by approximately 8 nm) than those obtained using the source "C" illuminant factors (Table 2). This is due primarily to the characteristics of the illuminant source because the source "A" illuminant is much richer in the red region of the visible spectrum than the type "C" illuminant.

Nelson et al. (1969) indicated that differences of 3.5% in luminance, of 4 nm in dominant wavelength, and of 5% in purity were visually detectable to one examining black walnut heartwood. The ranges reported in Table 2 for luminance and purity exceeded these limits. Dominant wavelength did not.

Moslemi (1967) suggested that differences in the luminance factors suggested differences in walnut heartwood color. Others have found variations in luminance and purity to be significant enough to be visually detectable in walnut heartwood (Nelson et al. 1969) and yellow poplar and black cherry (Sullivan 1967). Visual observations of the samples used in our study, however, agree with Moslemi's (1967) observation, i.e., variations in luminance were easily detectable with the unaided eye, but variations in dominant wavelength and purity were not. This suggested that the primary color factor that governed differences in walnut heartwood colorations was luminance. This criterion was used in subsequent statistical analyses.

As mentioned earlier, our preliminary evaluations suggested that much of the color variations occurred between trees within sites. No one site in our study produced trees of better color quality than the other sites. There appeared to be darker and nonuniform colored heartwood in some trees from each of the sites.

TABLE 4. *Mean veneer sheet heartwood luminance values (and standard deviations)—source "A" illuminant.*

	n[1]	Luminance (%)
Tree number 1		
Sheet 1	4	19.477[a][2] ± 1.366
Sheet 2	6	20.395[a] ± 1.912
Sheet 3	6	21.097[a] ± 2.828
Tree number 2		
Sheet 1	5	19.529[a] ± 0.927
Sheet 2	6	22.194[b] ± 2.164
Sheet 3	6	19.551[a] ± 1.025
Tree number 3		
Sheet 1	4	21.672[a] ± 0.588
Sheet 2	5	19.900[a] ± 1.692
Sheet 3	4	20.753[a] ± 1.632
Tree number 4		
Sheet 1	7	20.015[a] ± 1.579
Sheet 2	9	23.545[b] ± 3.802
Sheet 3	6	20.266[a] ± 2.648
Tree number 5		
Sheet 1	6	25.538[a] ± 1.906
Sheet 2	8	26.614[a] ± 1.944
Sheet 3	8	25.085[a] ± 1.879

[1] n = Number of observations.

[2] Values followed by the same superscript are not statistically different at the 0.05 level using the L.S.D. test. Similar trends were observed using the source "C" weighting functions.

This resulted in the emphasis being shifted to between-tree and within-tree color variations. Therefore, the data were examined using statistical procedures (analysis of variance) to test these relationships.

Heartwood luminance for the control tree (good quality veneer) was significantly higher than for the other trees (Table 3). Because good veneer quality was determined by uniformity in wood color and by a lighter brown color, this result was not surprising. It does lend credence to the use of the color parameters and their relation to visually detectable attributes. Statistically significant differences were also observed in sapwood luminance, i.e., the tree exhibiting highest sapwood luminance was significantly higher than two trees with the lowest mean luminance.

These same statistical analyses were continued in an attempt to analyze within-tree or sheet to sheet variations (Table 4). Statistically significant differences were observed in mean sheet luminance within two trees (numbers 2 and 4). These trees showed a statistically significant higher luminance in the middle sheet than in the other sheets. The middle sheet was removed near the center of the tree and thus was probably a more or less radial cut through the tree. The other sheets represented more oblique cuts and were more comparable with veneer used in industry. Even though there were statistically significant differences within two of the trees, these differences were marginal when compared to the visually perceptible difference range given by Nelson et al. (1969).

To estimate within-sheet color variations, confidence intervals (two standard deviations, alpha = 0.05) were computed around the mean heartwood luminance parameter within each sheet. There were wide ranges of luminance values within each sheet, but all values fell within the limits of the confidence intervals. Visually perceptible differences were observed in at least one instance. One sample was much darker (17.17% luminance) than another sample from the same veneer sheet (27.7% luminance).

These analyses strengthen the practicality of the color measurement technique toward applications in wood research, i.e., the luminance parameter accurately describes walnut wood color. Furthermore, Moslemi's (1967) reference to the uses of this technique to determine color differences is applicable. The importance of this technique lies not in generating pure descriptive numbers for a particular species but rather in comparing one species, one tree, one sheet of veneer, or one treatment type to another. Therefore, we must express the experimental technique used for the generation of these parameters and, if applicable, the micro-climate around a particular tree, the genetics of the tree, or the particular treatment that a piece of wood has undergone. Previous wood color studies, except for Nelson et al. (1969), have used wood from unknown origins. In order to realize more fully the potential of wood color research, more complete information is needed about the sample material.

CONCLUSIONS

This macroscopic study of the veneer of five black walnut trees reinforced the fact that color parameters (primarily luminance), obtained using spectrophotometric techniques, were comparable with visually perceptible attributes of color. These techniques are sensitive enough to repeatedly detect small differences in color parameters between different samples of veneer and were used to describe between-site, between-tree, and within-tree differences in wood color.

The luminance factor, a measure of lightness, was found to be the most important of the three color parameters measured—luminance, dominant wavelength, and purity. Visually detectable differences of light or dark chocolate brown color were readily apparent in those samples that varied widely in luminance. Variations in dominant wavelength and purity were not as easily distinguished visually.

Between-tree and, to some extent, within-tree variations in heartwood luminance were found to be more important than between-site variations for those trees studied.

REFERENCES

BECKWITH, J. R., III. 1974. An illustration of wood color measurement. Georgia For. Res. Council Pub. 74. Macon, GA. 6 pp.

BRAUNER, A. B., AND W. E. LOOS. 1968. Color changes in black walnut as a function of temperature, time, and two moisture conditions. For. Prod. J. 18(5):29–34.

JUDD, D. B. 1933. The 1931 I.C.I. standard observer and coordinate system for colorimetry. J. Opt. Soc. Am. 23:359–374.

LOOS, W. E., AND W. A. COPPOCK. 1964. Measuring wood color with precision. For. Prod. J. 14(2): 85–86.

MOSLEMI, A. A. 1967. Quantitative color measurement for black walnut wood. USDA For. Serv. Res. Paper NC-17. N.C. For. Exp. Sta., St. Paul, MN. 16 pp.

NELSON, N. D., R. R. MAEGLIN, AND H. E. WAHLGREN. 1969. Relationship of black walnut wood color to soil properties and site. Wood Fiber 1(1):29–37.

SULLIVAN, J. D. 1967. Color characterization of wood: Color parameters of individual species. For. Prod. J. 17(8):25–29.

Szopa, P. S., H. E. Garrett, and E. A. McGinnes, Jr. 1980. Growth-quality evaluation of black walnut wood. Part I. Specific gravity, growth rate, and percent extractables for trees grown on three different sites in Missouri. Wood Sci. 13(2):95–98.

Wright, W. D. 1969. The measurement of colour. 4th ed. Van Nostrand Reinhold Co., New York, NY. 340 pp.

Wyszecki, G., and W. S. Stiles. 1967. Color science: Concepts and methods, quantitative data and formulas. John Wiley and Sons, Inc., New York, NY. 628 pp.

Yen, C. P., C. H. Pham, G. S. Cox, and H. E. Garrett. 1978. Soil depth and root development patterns of Missouri black walnut and certain Taiwan hardwoods. Pages 36–43 *in* Proceedings of the Symposium on Root Form of Planted Trees, Victoria, B.C., Canada, 16–19 May.