# HEARTWOOD COLOR AND QUANTITY VARIATION IN A YOUNG BLACK WALNUT PROGENY TEST

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ABSTRACT

Black walnut heartwood color and quantity were evaluated from disks removed from 334 10-year-old trees at 30 cm above ground during thinning of a progeny test. Average tree height ranged from 3 to 7 m. Heartwood color variables (luminance, dominant wavelength, and purity) differed significantly by block, indicating that color is affected by environment. The darkest heartwood colors were associated with slower growth. No indication of genetic control over any heartwood color variables was observed. Heartwood quantity as measured by heartwood area was heritable; approximate narrow-sense heritability of heartwood area was 0.56. Heartwood area was positively correlated with total tree height and dbh, indicating that heartwood area is not sacrificed during selection for height or diameter in young stands. However, the correlations between sapwood area and height and diameter were greater than those with heartwood area.

*Keywords:* *Juglans nigra* L., luminance, heritability, heartwood area, specific gravity.

Future walnut plantations will likely be managed with short-rotation intensive culture. Under such management, heartwood-sapwood ratios may decline substantially (Nelson 1976; Szopa et al. 1980). Because walnut veneer logs cannot be steamed long enough to stain the sapwood, a practice widely used for walnut intended for other uses, wide sapwood bands may become a problem for future walnut managers.

Although we have no information on genotypic variation in the rate of walnut heartwood formation, significant variation in heartwood-sapwood ratios among trees in even-aged stands suggests that the potential exists for selecting walnut for rapid early heartwood formation. For example, Nelson (1976) conservatively estimated that it was possible to decrease by 5 to 11% the thickness and the number of sapwood rings per generation using standard tree improvement selection techniques.

Although researchers have attempted to relate walnut heartwood quality traits to environmental characteristics (i.e., soil and site variables), results have thus far been more suggestive than definitive. For example, Maeglin and Nelson (1970) found no statistically significant differences in wood color (i.e., luminance) among different site classes. However, trees with darker, redder heartwood tended to be found on poorer sites. Correlations between chemical soil properties and wood color were also weak (Nelson et al. 1969).

Results of two studies of black walnut heartwood properties have shown that variation among trees within stands is greater than variation among trees from different stands (Nelson 1976; Phelps et al. 1983). Such variation patterns are traditionally interpreted as indicating that genotypic control over a given trait is more important than the environmental effect. Unfortunately, no genetic controls were available for the trees in either study. Both studies implied that genetic

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TABLE 1. *Overall tree averages and ranges for several characteristics of black walnut heartwood and sapwood.*[1]

| Characteristic | Tree average | Range among trees |
|---|---|---|
| Heartwood | | |
| % Luminance | 22.2 | 12.1–35.5 |
| Purity | 28.8 | 16.2–44.6 |
| Dominant wavelength (nm) | 591.4 | 583.5–601.6 |
| Area ($mm^2$) | 354.4 | 78.5–1,772.1 |
| % Area | 14.0 | 3.9–57.3 |
| Thickness (mm) | 10.6 | 5.0–23.8 |
| Sapwood | | |
| Area ($mm^2$) | 2,264.4 | 410.6–6,597.4 |
| Thickness (mm) | 18.1 | 4.5–33.8 |
| Heartwood/sapwood area ratios | 0.170 | 0.040–1.34 |

[1] Based on sample size of 334 trees.

control over heartwood quantity and quality is substantial and should be studied further.

## METHODS

A half-sib black walnut progeny test was thinned in early 1983, ten growing seasons after establishment. Details of plantation establishment and site characterization are set forth elsewhere (Rink 1984). At the time the progeny test was thinned, tree growth differed greatly, averaging almost 7 m in height in some blocks and 3 m in others.

Thinning consisted of removing three of five trees per plot in each of ten blocks; disks were collected from only six blocks containing the largest trees. The two trees retained in each plot were the tallest, most vigorous, and/or best formed. A 3- to 5-cm cross-sectional disk was removed at 30 cm above the ground from each thinned tree. Disks were air-dried until they were evaluated, at which time they averaged 8.4% moisture content.

Data were analyzed by analyses of variance (ANOVA), correlation, and regression. The format of the ANOVA was a two-way model with blocks, families, and their interaction computed on an individual-tree basis. All effects in the model were assumed to be random. Approximate narrow-sense family heritabilities were calculated using the method of Kung and Bey (1977) where $h^2 = (1 - 1/F)$. The method is used when the value of $F$ (the calculated Fisher statistic used for testing significance) is found to be statistically significant among half-sib families.

Correlation and regression analyses on an individual-tree basis were applied to the complete data set, which included 334 disks. In order to minimize bias due to missing trees (e.g., mortality) in the ANOVA, disks from only the three blocks with the fastest growing trees were included; this was done primarily to balance the data set.

Wood disks were evaluated for the following traits:

1. *Inside bark diameter:* This was determined by averaging two diameter measurements taken at the widest point and at a plane perpendicular to it. Branch scars were avoided in these measurements.

TABLE 2. *Probabilities of larger* F-*values in analyses of variance and narrow-sense heritabilities*[1] *for several properties.*

| Source of variation | Wood properties | | | | | |
|---|---|---|---|---|---|---|
| | Heartwood luminance | Heartwood dominant wavelength | Heartwood purity | Heartwood area | % Heart-wood area | Sapwood area |
| Block | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| Half-sib family | 0.14 | 0.72 | 0.19 | <0.01 | 0.17 | 0.05 |
| Block × family | 0.26 | 0.47 | 0.38 | 0.04 | 0.14 | 0.65 |
| Heritability | — | — | — | 0.56 | — | 0.40 |

[1] Heritabilities calculated only when $F < 0.05$ for family effect; ANOVA based on a sample size of 143.

2. *Heartwood width:* This was determined by measuring the width along the same planes as the diameter measurements. Heartwood area was determined as the area of a circle ($A = \frac{1}{4}\pi D^2$) using the mean heartwood diameter. The difference between total disk cross-sectional area and heartwood area was defined as sapwood area.

3. *Heartwood color:* This was determined after cutting disks along the longest axis, slightly off center to avoid the pith. This radial surface was lightly sanded and applied to a reflectance attachment on a Bausch and Lomb Model 20 spectrophotometer to measure reflectance at 30-nm intervals in the visible spectrum (400 to 700 nm). The reflectance attachment was equipped with a "Type C" light source, representing average daylight (Moslemi 1967). Procedures outlined by Phelps et al. (1983) were used to calculate luminance (lightness or brightness), dominant wavelength (hue), and purity (light saturation) for each disk.

## RESULTS

Average values and ranges for several heartwood and sapwood characteristics were calculated (Table 1). Analyses for thickness and disk cross-sectional area variables were very similar; hence only the area analyses are presented. Average values for heartwood percent luminance, dominant wavelength, and percent purity correspond closely to values presented by Nelson et al. (1969) and Phelps et al. (1983).

Results of analyses of variance disclosed significant block effects for all variables evaluated (Table 2). Significant block effects imply strong environmental influence over color and growth variables and also reflect efficient blocking in the progeny test. Statistically significant family effects were obtained only for heartwood and sapwood area indicating genetic control over these variables; approximate half-sib family heritabilities for them were 0.56 and 0.40, respectively. None of the heartwood color variables were significant for the family effect. Apparently heartwood color is not strongly genetically controlled and is influenced more by environmental variables than by heredity. The interaction of blocks and families was also not significant; however, this interaction effect was significant for heartwood area.

Correlation analyses disclosed that of the three color variables, only luminance had any meaningful and statistically significant relation with growth variables (Table 3). Luminance was positively correlated with both height and diameter in 1982 ($r = 0.33$ and $0.23$, respectively), indicating that heartwood color was lighter

TABLE 3. *Pearson's correlations and the probabilities (P) of obtaining greater* r *values among several wood properties.*

| | HWA | HWA % | SWA | H/S | H 77 | H 82 | D 82 | LY | DWL | Purity |
|---|---|---|---|---|---|---|---|---|---|---|
| Heartwood area (HW) | | 0.62 | 0.48 | 0.55 | 0.36 | 0.41 | 0.48 | 0.16 | −0.05 | 0.07 |
| *P* | | 0.00001 | 0.00001 | 0.00001 | 0.00001 | 0.00001 | 0.00001 | 0.0005 | 0.61 | 0.17 |
| % Heartwood (HWA %) area | | | −0.28 | 0.93 | 0.09 | −0.10 | −0.08 | 0.05 | 0.04 | 0.10 |
| *P* | | | 0.00001 | 0.00001 | 0.10 | 0.06 | 0.15 | 0.59 | 0.51 | 0.07 |
| Sapwood (SWA) area | | | | −0.24 | 0.36 | 0.66 | 0.73 | 0.14 | −0.07 | −0.0008 |
| *P* | | | | 0.00001 | 0.00001 | 0.00001 | 0.00001 | 0.0008 | 0.21 | 0.88 |
| Heartwood/sapwood area (H/S) | | | | | 0.04 | −0.09 | −0.09 | 0.08 | 0.02 | 0.09 |
| *P* | | | | | 0.51 | 0.09 | 0.10 | 0.13 | 0.68 | 0.11 |
| Height 1977 (H77) | | | | | | 0.56 | 0.53 | 0.04 | 0.12 | 0.05 |
| *P* | | | | | | 0.00001 | 0.00001 | 0.52 | 0.03 | 0.65 |
| Height 1982 (H82) | | | | | | | 0.84 | 0.33 | −0.09 | 0.04 |
| *P* | | | | | | | 0.00001 | 0.00001 | 0.10 | 0.52 |
| DBH 1982 (D82) | | | | | | | | 0.23 | −0.02 | 0.02 |
| *P* | | | | | | | | 0.00001 | 0.66 | 0.75 |
| Luminance (LY) | | | | | | | | | 0.43 | 0.39 |
| *P* | | | | | | | | | 0.00001 | 0.00001 |
| Dominant wavelength (DWL) | | | | | | | | | | −0.26 |
| *P* | | | | | | | | | | 0.00001 |

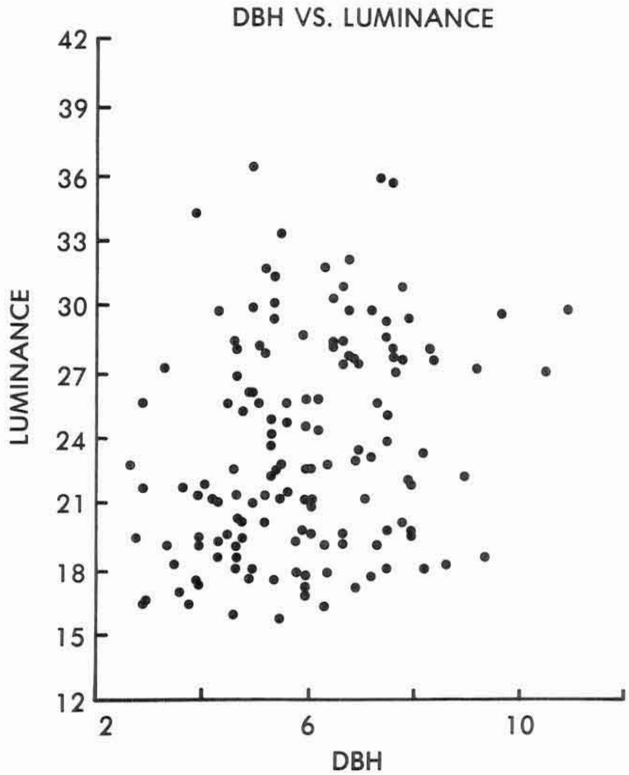


FIG. 1. Heartwood luminance values (%) of 143 trees plotted against diameter breast height (cm).

in faster growing trees. In spite of this correlation, the relation was weak (Fig. 1); variation in 1982 height and diameter accounted for only 11 and 5% of variation in luminance, respectively, and no correlation was found between color and 1977 height. It is possible, therefore, that the correlation may become stronger with increasing age.

Both heartwood and sapwood disk cross-sectional areas were also significantly correlated with 1977 height and 1982 height and diameter at breast height. Furthermore, height and dbh were much more highly correlated with heartwood and sapwood areas than with color variables. Although the individual-tree correlation between sapwood area and height and diameter was higher than with heartwood area (Fig. 2), it is encouraging to know that selection for increased height and diameter growth also results in increased heartwood quantity. (The relation between disk diameter and heartwood diameter appeared to be linear and positive.)

## DISCUSSION

Heartwood percent luminance is the best measure of heartwood color (Phelps et al. 1983). Results from several previous studies have implied that luminance is affected by soil environmental variables (Nelson et al. 1969; Maeglin and Nelson 1970). Statistical differences among blocks for luminance in the present study could be interpreted as soil variables affecting luminance; the darkest heartwood (avg. % luminance = 19.3) was associated with the block with the poorest growth,

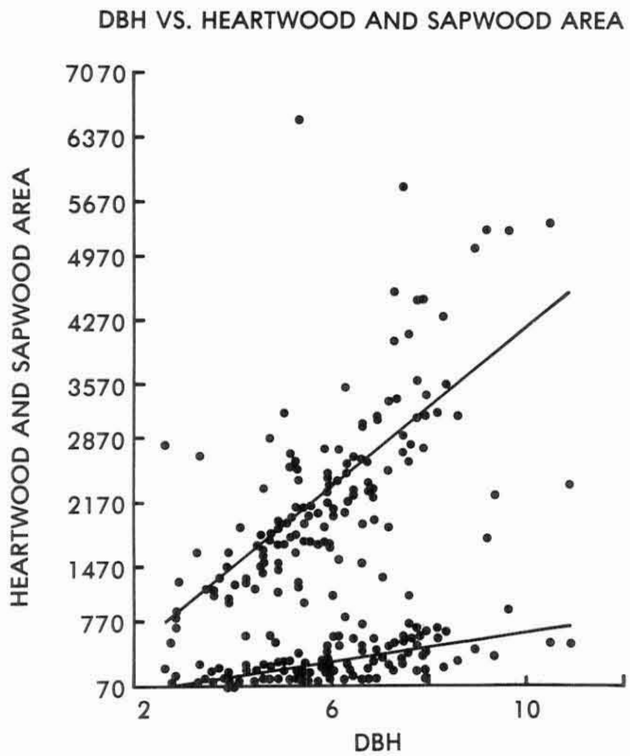


FIG. 2. Heartwood and sapwood area ($mm^2$) of 143 trees plotted against diameter breast height (cm). The lower line represents the relation between heartwood area and diameter and the upper line represents the relation between sapwood area and diameter.

while the lightest heartwood was found in trees with the fastest average growth (avg. % luminance = 29.1). This relation was also reflected in the positive correlations between luminance and height and diameter growth (higher luminance values indicate lighter colors). However, this relation partly results from the influence of "figure"; slower growth and the associated narrower annual rings will always result in lower luminance values.

Darker heartwood color is significantly correlated with increased content of heartwood extractives (Hiller et al. 1972), which consist primarily of insoluble highly polymerized phenolic compounds biosynthesized in parenchyma cells (Nelson 1975). Hillis (1975) suggested that polyphenol formation in woody tissues is related to ethylene production and that its production increases as stress increases. In black walnut this would seem to be substantiated by a study of xylem ethylene production on two sites; the highest ethylene yields were on the site with the slower growth (Nelson et al. 1981). Presumably slower growth in that plantation is the result of higher stress compared to the plantation with faster growth. Similarly, Phelps and McGinnes (1983) suggested that increased stress results in greater production of polyphenols. Nelson et al. (1981) also found no indication of genetic differences in ethylene production among half-sib families. In the present study, ethylene production was not studied, but results of the above studies are consistent with ethylene production contributing to differences among blocks and a lack of differences among half-sib families in percent luminance. However, ethylene physiology involves interactions with auxins and therefore may be related to heartwood formation in a complex manner.

The high heritabilities obtained in this study for heartwood and sapwood cross-sectional area confirm Nelson's (1976) prediction that narrow-sense heritability for sapwood area and thickness would substantially exceed 0.20. The high heartwood area heritability implies that considerable genetic gains could be achieved by selection for this trait. For example, selection of 20% of the trees with the greatest heartwood area translates to a selection intensity of 1.4 and results in an increase of 185.7 $mm^2$ of heartwood area in one generation; this is equivalent to an expected genetic gain of 49%. However, because heartwood and sapwood area are significantly positively correlated ($r = 0.48$), a simultaneous increase in sapwood area would also be expected.

Unfortunately, our selection programs cannot take into account heartwood area, because we cannot tell by looking at a tree how much heartwood it has. Most selection is on the basis of height, diameter, and form. In the present study, the tallest 20% of the trees had 38% greater heartwood area than the overall average (548 vs. 396 $mm^2$). These same trees also had 44% greater sapwood area than the overall average. Therefore, by this selection approach, we get a greater increase in sapwood than in heartwood area. However, if we had selected the tallest four families on the basis of their mean height, we would have obtained a 23% increase in heartwood area and only a 24% increase in sapwood. By the latter approach, an increase in sapwood is minimized, although some heartwood gain is also sacrificed. In practice, selection would be on the basis of some combination of family and individual tree characteristics and would result in some intermediate increase in both heartwood and sapwood area. However, it is encouraging to know that we do not sacrifice heartwood quantity when we select trees on the basis of size.

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