RADIAL AND VERTICAL VARIATION IN STEM PROPERTIES OF JUVENILE BLACK LOCUST (*ROBINIA PSEUDOACACIA*)

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ABSTRACT

Ten 10- to 12-year-old black locust (*Robinia pseudoacacia* L.) trees from two sites were analyzed to determine the within-tree variation (radially and vertically) and the between-site variation of selected wood properties. Specific gravity, fiber length, and extractive content exhibited significant radial variation for samples taken at breast height. Specific gravity increased radially from 0.57 near the pith to 0.68 near the cambium. Fiber length also increased radially from 0.75 mm (pith) to 1.06 mm (cambium). Radial variation was also exhibited by benzene-EtOH and total extractive content. Sapwood tissue possessed the lowest benzene-EtOH content (2.70%) and total extractive content (6.81%), while the outer heartwood tissue maintained the highest extractive levels, 4.60% and 8.54%, respectively. Vertical stem analysis of samples obtained at intervals of 20% of the total-tree height showed a positive relationship with height, for ash content and hot-water extractive content, and a negative relationship with height for fiber length and benzene-EtOH extractive content. Stem tissue was composed of 84.7% wood and 15.3% bark. Mean heartwood content was 54.1%. Total stem-wood fiber length, specific gravity, and total extractive content averaged 1.05 mm, 0.68 and 7.32%, respectively. Nonextracted specific gravity was the only property differing significantly between sites averaging 0.69 and 0.66 for the two sites.

Keywords: Black locust, juvenile wood, specific gravity, fiber length, extractive content.

INTRODUCTION

In 1601 black locust (*Robinia pseudoacacia* L.) was the first tree species to be exported to Europe from North America. Since that time extensive plantings in excess of 1×10^6 ha have expanded the range of the species throughout temperate and Mediterranean zones of Europe and Asia. Currently black locust is one of the most widely planted broadleaf species in the world, ranked with *Populus* and second to *Eucalyptus* in total hectares established (Kereszleski 1981). Because of its ease of regeneration, rapid growth rate over a wide range of sites, and favorable wood qualities, black locust is considered a valuable species across the majority of its cultivated range. Throughout much of its native North America, however, persistent attacks by endemic populations of *Megacyllone robiniae* (locust borer) and later infestation by *Phellinus* (*Fomes*) *rimosus* causing severe heartrot, have reduced the status of the species to a weed tree. Because of these problems even conventional uses such as poles, pilings, and lumber are now negligible.

One of the primary uses of black locust in North America is for surface-mine revegetation. Widespread utilization of the species in reclamation has produced thousands of hectares of monoculture stands throughout the coal field regions of eastern North America. These plantings represent an as yet untapped source of woody biomass, and several researchers have advocated the use of these stands as a source of biomass fuel (Carpenter and Eigel 1979; Stringer and Carpenter

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1982). Carll and coworkers (1985) recently suggested that black locust may have potential for use in producing some types of composite materials. Whether potential uses of this young biomass encompass chipped or sawn products, adverse effects from a large proportion of juvenile wood are a possibility (Senft et al. 1985). Initially, many wood property studies employed older mature trees for sampling, and subsequently little information has been obtained on juvenile wood properties of many species, especially hardwood species. Problems arising from the lack of information on younger material are accentuated when considering whole-tree or main-stem chipping. These types of harvesting practices increase the proportion of juvenile wood compared to more conventional butt log utilization.

No information could be found describing the within-tree variation of the wood properties of black locust. However, limited investigations of the vertical variability of specific gravity (SG) and fiber length have been undertaken for a few selected southern hardwood species. Manwiller (1979) examined twenty-two small diameter hardwood species and found that SG tended to remain relatively stable or decreased slightly with sampling height in the majority of species studied. Taylor (1979) also found no correlation between sampling height and SG in six of eight southern U.S. hardwood species. Overall trends of Taylor's study trees suggested slightly greater SG at the groundline and crown positions. Ezell and Schilling (1979) obtained an inverse relationship between height and fiber length in *Liquidambar styraciflua* L.

Literature showing radial variation in SG, fiber length, or total extractive content of black locust could not be located. Limited data, however, are available for water extractive contents of sapwood and heartwood. Ritter and Fleck (1926) obtained higher heartwood extractive contents ($\bar{x}$ = 11.04%) compared with the sapwood ($\bar{x}$ = 3.91%), while Hart (1968) found no statistical ($P > 0.05$) difference between hot-water extractive content of heartwood ($\bar{x}$ = 8.6%) and sapwood ($\bar{x}$ = 9.7%).

The primary objective of this study was to examine the within-tree variability of selected wood properties of young black locust trees. Because much of this young material may be potentially utilized on a whole-tree or main-stem basis, average main-stem values were determined for SG, fiber length, extractive content, bark percentage, and ash content. While the use of the species as a potential biomass fuel has been suggested, caloric content determination was not included in this study as it has been previously determined for young black locust (Stringer et al. 1982).

SAMPLING AND METHODS

Ten codominant black locust trees were randomly selected from two monoculture stands (5 from each stand) located on reforested surface-mined sites on the Cumberland Mountain (site I) and Cumberland plateau (site II) physiographic regions of eastern Kentucky. Both stands had been established by direct seeding of mixed shale and sandstone spoils. The stands situated on broad ridge-tops were homogeneous with regard to spoil and topography. The 10- to 12-year-old trees averaged 10.5 m in height and 12.6 cm in diameter at breast height (1.4 m above groundline). To allow for future sample orientation, zero degrees north azimuth was delineated on each tree prior to felling at the groundline. Vertical stem analysis was completed on 20-cm-long stem sections removed from the main-stem at 0, 20, 40, 60, and 80% of total-tree height. The diameter inside bark at each 20% interval was measured. Radial analysis was completed on the stem samples obtained at breast height.

Vertical stem analysis

While in the green condition, three 1-cm-thick cross-sectional discs were removed from the middle of each stem sample for examination. The first disc was debarked and utilized for SG determination using the water immersion method. Specific gravity was calculated on a green volume, oven-dry mass basis. Heartwood and sapwood percentages were determined from the second disc using whole-disc and heartwood tracings passed through a leaf area meter. Mean diameters inside and outside bark were calculated from radii measured in the four cardinal directions and used to estimate wood and bark volumes. Extractive contents were determined from either half or the entire second disc depending on disc size. Debarked extraction samples were prepared according to TAPPI standards (TAPPI 1968). Extraction times were 8, 8, and 4 hours for benzene-EtOH, 95% EtOH and hot-water, respectively. The samples were oven-dried to constant mass at 103 C and weighed after each successive extraction. Extractive contents were determined based upon initial oven-dry mass.

A random azimuth was selected for each tree, and a 0.5-mm wide sliver containing the last 2 years of growth was excised from the radial surface of the third 1-cm-thick disc at each sampling height. Fiber length was measured using the methods outlined by Jourdain and Olson (1984). Ash content was determined using a ground 1 g composited wedge sample from the third disc according to ASTM D1102-50T.

Total main-stem volumes[1] and mean values for each property measured were calculated using the truncated-cone method of Wahlgren and Yandle (1970). The sample diameter inside bark at each sampling height was employed in the truncated-cone weighting procedure. The main-stem values represent a weighted average based on the cross-sections sampled and the relative amount of volume represented by each cone between each sample height.

Radial stem analysis

Two 12-mm-thick discs were cut from each cross-section at breast height for radial stem analysis. The first disc was quartered. One defect-free quarter-section was used for SG measurements and a second quarter used for fiber length determination. The quartered discs for both of these analyses were divided into 2-year increments moving radially from the pith. Specific gravity analyses were conducted on the entire 2-year increment and a 0.5-mm-wide sliver taken across each increment was used for fiber length measurements. The second disc was halved and each half divided into four parts corresponding to the sapwood, sapwood-heartwood transition (one growth ring on either side of the visual boundary), outer heartwood, and inner heartwood. The last two portions were separated based on age. These samples were used for determination of successive extractive content.

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[1] Total main-stem volume was defined as the bole or trunk of the tree from the groundline to 80% of the total-tree height.

TABLE 1. *Vertical stem analysis of selected wood properties of 10- to 12-year-old black locust.*[1]

Total tree ht (%)	Specific gravity	Fiber length (mm)	Ash content (%)	Heartwood content (%)	Extractive content (%)			
					Benzene-EtOH	EtOH	Hot water	Total
0	0.69 ns	1.06 a	0.56 a	65.9 a	3.7 a[2]	1.1 ns	2.7 a	7.6 ns
20	0.67	1.09 a	0.60 a	65.9 ab	3.4 ab	1.0	2.7 a	7.1
40	0.67	1.03 a	0.62 a	52.0 b	3.3 ab	0.9	2.7 a	7.0
60	0.67	0.96 b	0.84 b	32.5 c	2.8 b	1.4	3.0 a	7.2
80	0.68	0.90 b	0.87 b	13.2 d	2.7 b	1.2	3.5 b	7.4

[1] n = 10 measurements obtained from cross-sectional disks. Fiber length measurements from outer 2 rings.
[2] Values followed by a different letter within a column are statistically different at $P \geq 0.05$ using ANOVA and Duncan's multiple range test.

Analysis of variance and Duncan's multiple range test were used to test for statistical differences between sampling heights with regard to extractive contents, SG, fiber length, ash content, and heartwood content. The same techniques were used to determine statistical differences in extractive content, SG, and fiber length among 2-year radial increments of breast-height samples. Statistical analysis was used to determine differences between planting sites for the properties examined in the radial analysis.

RESULTS AND DISCUSSION

Vertical analysis

Significant statistical differences were found among sampling heights in fiber length, ash content, extractive content, and heartwood content (Table 1). Specific gravity did not differ statistically among sampling heights ($\bar{x} = 0.67$), but showed a trend of slightly higher SG at the groundline and upper crown position similar to the results of Taylor (1979). Ash content exhibited a positive relationship with tree height ranging from a mean of 0.56% at the groundline to 0.87% at 80% of total-tree height ($P \leq 0.01$). Fiber length was inversely related to height. The longest fibers were located at 20% of total-tree height ($\bar{x}$ = 1.09 mm) and were statistically different ($P \leq 0.01$) from the fibers at 60 or 80% total-tree height ($\bar{x}$ = 0.90 mm). Heartwood content decreased from a mean of 65.9% at groundline to 13.2% at 80% of total-tree height.

Total extractive content did not vary significantly among sampling heights. However, benzene-EtOH and hot-water extractive content varied significantly ($P \leq 0.01$) among sampling heights (Table 1). Benzene/EtOH extractive content exhibited an inverse relationship to height with a mean groundline value of 3.7% decreasing to 2.7% at 80% of the total-tree height. Hot-water extractive content varied positively with height, increasing from a mean of 2.69% at the groundline to 3.50% at 80% total-tree height. EtOH extractive content did not vary significantly between sampling heights ($P > 0.05$). Polar extractive content (EtOH and hot-water) exhibited a positive vertical relationship, averaging 3.83% at the groundline and 4.70% at the upper crown position. This pattern is opposite the trend normally found in most *Pinus* species.

Radial analysis

Both SG and fiber length exhibited a significant ($P \leq 0.01$) radial increase from near the pith to the cambium at breast height (Fig. 1). Mean 2-year increment

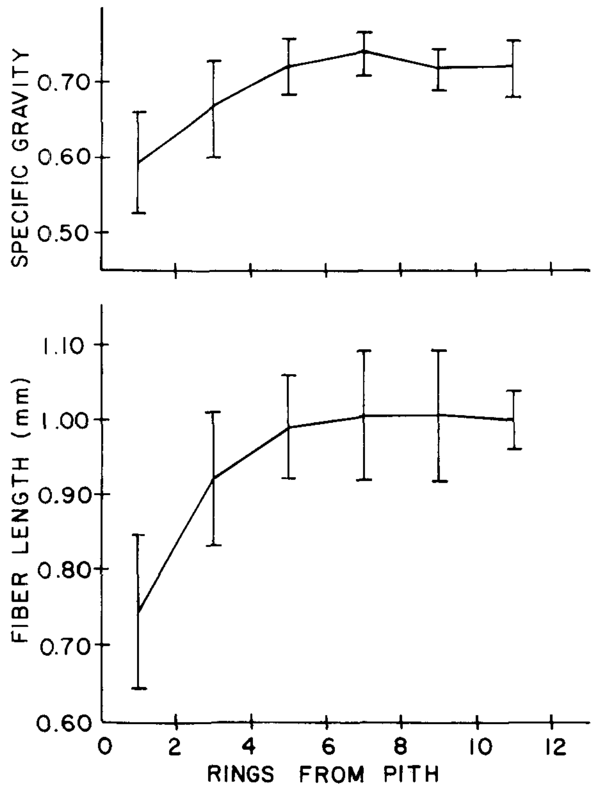

FIG. 1. Radial variation in specific gravity and fiber length. Each point represents the mean value from 10 trees (bars ± SE).

SGs increased from 0.57 near the pith to 0.67 in the outer 2-year increment. Individual samples varied from 0.47 to 0.74, with the greatest variation present in the increments nearest the pith (CV = 9.5%). The remaining increments were stable with CVs between 3.4 and 4.3%. Average fiber lengths increased from 0.75 mm nearest the pith to 1.06 mm adjacent to the outermost 2-year increment.

Radial variation in both fiber length and SG was characteristic of the transition between juvenile and mature wood in the main stem-wood as found in most

TABLE 2. *Radial analysis of fractionated extractives of young black locust.*

Radial position	Extractive content			
	Benzene-EtOH	95% EtOH	Hot water	Total
	% O.D. mass			
Inner heartwood	4.1 (0.81) a[1]	0.8 (0.24) ns	3.3 (0.87) ns	8.2 (1.40) a
Outer heartwood	4.6 (0.60) a	0.9 (0.32)	3.1 (0.54)	8.5 (0.89) a
Transition zone	4.0 (1.21) a	0.9 (0.23)	3.0 (0.37)	7.9 (1.57) ab
Sapwood	2.7 (1.05) b	0.9 (0.24)	3.2 (0.55)	6.8 (1.16) b
x̄	3.9	0.9	3.2	7.9

[1] Standard errors in parentheses. Values represent the mean from samples taken 1.4 m above groundline (n = 10). Entries followed by a different letter are statistically different at $P \geq 0.05$ using ANOVA and Duncan's multiple range test.

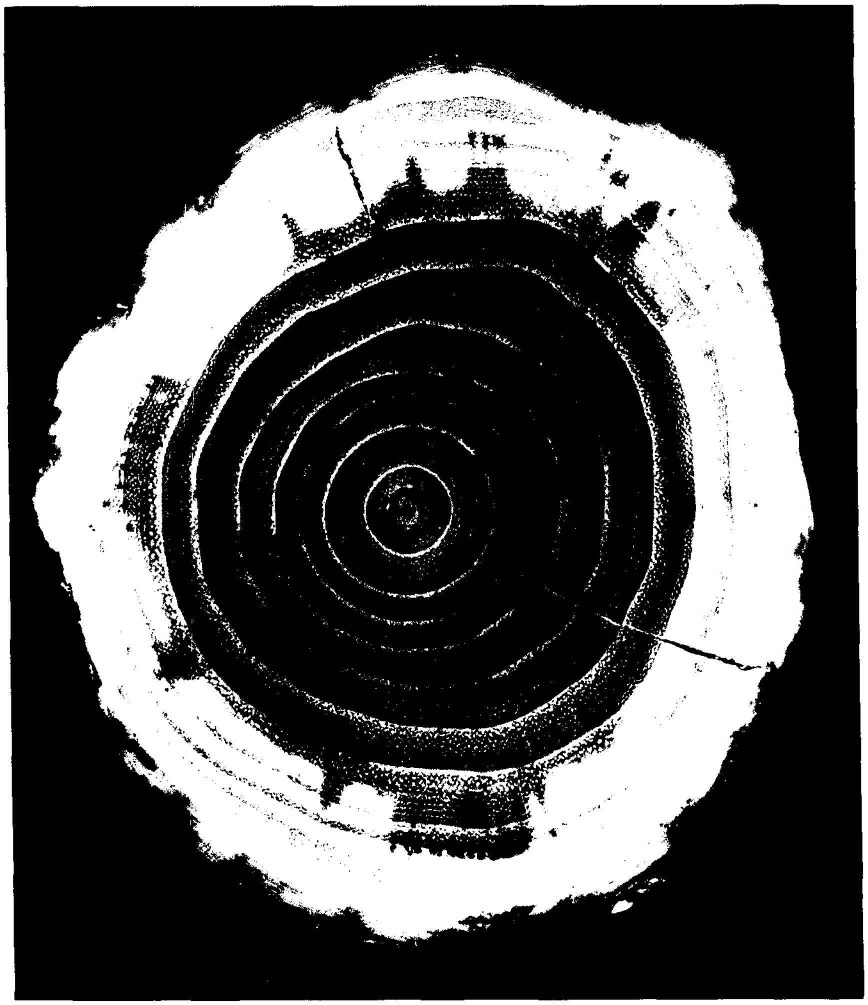

FIG. 2. Typical cross-section of black locust stem-wood showing uneven annular distribution of pigmented extractives.

species. Juvenile fibers are normally shorter than mature fibers. In this study fiber length increased over the first 8 annual increments then remained relatively constant over the next four increments. Specific gravity also exhibited this same pattern. The radial trends exhibited by SG and fiber length suggest that a core of juvenile wood was produced during the first 8 years of xylem production. This 8-year core of juvenile wood falls within the lower bounds of the 5- to 20-year range of juvenile wood production normally found in conifers (Bendtsen 1978).

Benzene-EtOH and total extractive contents showed statistically significant radial variability ($P \leq 0.01$). EtOH and hot-water extractives did not exhibit significant radial variation with overall mean values of 0.9% and 3.1%, respectively (Table 2). Benzene-EtOH extractive content was 70% higher in the outer heartwood versus the sapwood. The increase in the benzene-EtOH extractive content

TABLE 3. *Mean main-stem values, coefficients of variation, and individual tree ranges for wood properties of young black locust.*

Property	Mean	Coefficient of variation	Individual[1] tree range
Volume (m^3)	0.04337	16.1	0.03070–0.05470
Wood (%)	84.7	4.7	80.0–86.3
Bark (%)	15.3	26.1	11.2–20.0
Heartwood (%)	54.1	15.2	34.8–60.2
Sapwood (%)	45.9	17.9	39.8–65.2
Specific gravity	0.68	2.9	0.65–0.71
Ash (% dry mass)	0.62	12.9	0.47–0.74
Fiber length (mm)	1.05	7.6	0.94–1.11
Extractives (% dry mass)			
Benzene-EtOH	3.5	17.1	2.7–3.9
EtOH	1.1	27.3	0.7–1.6
H_2O (hot)	2.8	7.1	2.4–3.1
Total	7.3	9.6	6.2–8.3

[1] Represents the mean individual tree range among trees, $n = 10$. Fiber length values are averaged from the outer 2 increments.

was primarily responsible for the significant increase ($P \leq 0.01$) in the total extractive content of the outer heartwood compared to the sapwood. In both instances the inner heartwood, outer heartwood, and transition zones were not significantly different from each other.

Many of the sample cross-sections exhibited a wide degree of variation in the visible heartwood-sapwood boundary often leading to many inclusions of pigmented extractives into the outer transition and sapwood zones (Fig. 2). These heartwood extensions were not a result of any apparent tissue damage and do not display characteristics of discolored sapwood as discussed by Hart (1968).

Main-stem analysis

Total main-stem volume averaged 4.337×10^2 m^3/tree with 3.673×10^2 m^3 (84.7%) occupied by wood and 0.663×10^2 m^3 (15.3%) composed of bark (Table 3). The mean SG was 0.68 (CV = 2.9%) for the main-stem, which is greater than any of the 22 species of young hardwoods studied by Manwiller (1979). The species with the highest main-stem SG in Manwiller's study was *Quercus stellata* Wangenh. ($\bar{x} = 0.66$). The weighted mean stemwood value found for the black locust trees in this study ($\bar{x} = 0.68$) was higher than the mean of 0.66 reported in the *Wood Handbook* (USDA Forest Products Lab 1978). Manwiller (1979) also found the mean stem-wood SG's of the species he studied to be higher than the values obtained from mature trees sampled by the USDA Forest Products Lab.

Mean main-stem ash content was 0.62%, slightly less than the mean value of 0.65% obtained by Neenan and Steinbeck (1979) for nine species of young hardwoods. Both are higher than the normal range (0.1–0.5%) reported by Panshin and deZeeuw (1980) for native North American hardwoods. Mean main-stem fiber length was 1.05 mm, slightly shorter than the average for all hardwood species (1.13 mm) reported by Panshin and deZeeuw (1980). Mean main-stem total extraction content averaged 7.3%, ranging from 6.2 to 8.3%. The values are consistent with those obtained by Stringer et al. (1982) for 20-year-old black locust clonal stem-wood with an overall average of 7.6% with mean clonal values ranging from 6.9% to 8.7%.

Site variation

Specific gravity was the only property analyzed that varied significantly between sites ($P \leq 0.01$). Trees from site I had a slightly higher mean SG of 0.69 as compared with 0.66 for site II. However, this small difference may not be of practical significance. Whether this variation is attributable to site or genotypic variation is not known. If the specific gravity measurements were adjusted for extractive content, the two sites were not significantly different with an overall mean of 0.63. Although SG differed between sites, the variability was not associated solely with the last few years of growth as experienced by Foster and Thor (1979) for 11- to 12-year-olds.

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