

## Variation of Specific Gravity in Plantation-Grown Trees of Bigleaf Mahogany

by

C. B. Briscoe,

J. B. Harris,

and D. Wyckoff

### S U M M A R Y

As a prelude to tree improvement work in the genus *Swietenia*, a study was made of specific gravity variation within the bole of six plantation-grown trees of bigleaf mahogany.

Variation was appreciable, from 0.36 to 0.65, and several patterns were determined. Specific gravity of the tree increased with growth rate, as expressed in diameter at breast height, but not with relative length of radius at a given height in a particular tree. It increased outward from the pith; but it was high at the base, dropped markedly to a minimum at eight feet, then increased to near the base of the crown. There was no clear correlation with direction, but in these trees the wood at heights of 22 and 29 feet is heavier along the west radius.

Tree specific gravity can be estimated from specific gravity at the pith at 1-foot height,  $r = 0.618$ , or from core specific gravity and growth, as expressed by diameter breast high and merchantable height,  $r = 0.987$ .

### R E S U M E N

Como un preludio del trabajo para el mejoramiento de árboles del género *Swietenia*, se hizo un estudio de la variación del peso específico dentro de los troncos de seis árboles de caoba de hoja grande crecidos en plantación.

La variación fue apreciable, de 0.36 a 0.65 y se determinaron varias tendencias. El peso específico del árbol aumentó con la rapidez de crecimiento en el diámetro a la altura del pecho, pero no con la longitud relativa del radio a una altura dada de un árbol en particular. El aumento fue desde la médula hacia afuera; pero fue mayor en la base, disminuyó notablemente al mínimo a los 8 pies de altura y luego aumentó hasta cerca de la base de la copa. No se registró una correlación clara con la dirección, pero en estos árboles la madera a una altura de 22 y de 29 pies es más pesada en el radio oeste.

El peso específico de un árbol puede estimarse del peso específico en la médula a un pie de altura,  $r = 0.618$ , o del peso específico del centro y el crecimiento, según lo demuestra el diámetro a la altura del pecho y la altura comerciable,  $r = 0.987$ .

"Specific gravity of wood is of practical interest because it is the best single criterion of strength" (Desch 1938, page 58). Continued study has supported this basic premise (Kraemer 1956, Nicholls & Dadswell 1960, Radcliffe 1953).

Tree improvement, particularly, requires an estimation of the quality of standing trees,

and the present study was primarily to provide background information for a proposed tree improvement program<sup>1</sup> for bigleaf mahogany (*Swietenia macrophylla* King).

Knowledge of the entire merchantable portion of the stem is necessary, however,

<sup>1/</sup> Barres, H. 1963. Mahogany provenance study plan. U.S. Forest Service, Institute of Tropical Forestry, Río Piedras, Puerto Rico.

and the objectives of this study were (1) to determine whether specific gravity varies within a tree and, if so, (2) to study the pattern of variation.

### PREVIOUS WORK

Gymnosperms have now been studied fairly extensively (Spurr & Hsiung 1954, list 87 references) and variation has been found to occur. The pattern is fairly well accepted as being essentially that described by Chevandier in 1848.

(1) Specific gravity increases with age, fairly rapidly at first and later very slowly if at all. In some species, at least, there are reports (Desch 1932, Sekhar & Negi 1961, Spurr & Hsiung 1954) that wood produced by overmature trees is lighter than that produced earlier. This pattern is the same at any given height in a tree. In spruce, at least, this normal pattern is modified in that the specific gravity next to the pith is relatively high drops off rapidly, then begins the normal increase with age (Bryan & Pearson 1955, Nylinder 1953).

(2) For wood laid down during a given year, specific gravity decreases with height. This pattern, also, is modified in spruce and similar species with indistinct summerwood and pronounced taper (Nylinder 1953, Spurr & Hsiung 1954). Specific gravity may even increase with height.

(3) There is no regular relationship of specific gravity with ring width. This point has been the subject of a great deal of controversy, chiefly because of the confounding of ring width with tree age and height in tree, see above, and with percentage of latewood, see below.

(4) Not mentioned by Chevandier, but extensively documented in this century (Larson 1957, Nylinder 1953) is that specific gravity varies with percentage of latewood, at least in those species with distinct latewood and earlywood (Spurr & Hsiung 1954).

Ring-porous hardwoods, particularly spe-

cies of *Quercus* and *Fraxinus* have also been studied, though less extensively. For these species, the proportion of latewood apparently far outweighs other considerations (Bethel 1943). Therefore, specific gravity tends to decrease with age and from the crown toward the tree stump, just as percentage latewood tends to decrease.

Diffuse porous hardwoods, a group which includes most tropical hardwoods, have been studied much less, and, despite McLintock's (1957, page 2) somewhat optimistic statement "In the case of hardwoods—both ring porous and diffuse porous—the facts are well established . . .", the results are apparently not consistent, even within a species.

(1) Specific gravity increased with age (Aung 1962; Stauffer 1892; Curro 1957, 1960; Anonymous 1948; Murthy 1959), or it increased for some trees and decreased for others (Lenz 1954), or—like spruce—it decreased at first then increased (Grossler 1943), or varied with age in the lower bole only (Gohre & Gotze 1956), or was simply irregular (Anderson & Moltesen 1955).

(2) Specific gravity decreased with height (Burger 1940, Tamolang & Balcita 1957, Stauffer 1892), or increased briefly then stabilized (Grossler 1943), or decreased upward a few meters then increased (Gohre & Gotze 1956), increased with height (Burger 1910, Curro 1957, Lenz 1954) in single rings as well as the entire disc (Curro 1960) or did not vary with height (Anonymous 1948, Greenhill & Dadswell 1940).

(3) Rapid growth may be associated with decreased specific gravity (Susmel 1953), increased specific gravity (Grossler 1943), no relation (Anonymous 1948, Lenz 1954, Gohre & Gotz 1956, Seaman 1926), or with increased specific gravity in some species and decreased specific gravity in others (Ghosh et al. 1958).

Since there is no clear distinction between early and late wood, their differences have not been studied.

Site, however, has often been thought to exert influence, certainly as it influences growth. In addition, Hartig (1897) felt that good sites produce fast growth of high density, as opposed to wide spacing yielding fast growth of low density. The results reported (Susmel 1953) fail to support this distinction. Altho Murthy (1959) reported no specific gravity variation in stems of swamp-grown timber of a species in which specific gravity increased with age on other sites, most studies have failed to correlate specific gravity with site *per se*.

The reader who wishes to review thoroughly the pertinent literature should begin with "The Influence of Environment and Genetics on Pulpwood Quality" (Forest Biology Committee, TAPPI 1962); the preceding indicate that variation does occur, but the pattern is certainly not universal among diffuse porous species.

### PROCEDURE<sup>2</sup>

Bigleaf mahogany is an exotic in Puerto Rico, so plantation-grown trees are the only ones available. To reduce extraneous variation, trees from only a single plantation were used, with one exception. A preliminary analysis failed to show the single tree different from the other five, so the data were combined.

Before felling, each tree was marked with the four cardinal directions and a reference height.

Immediately after felling the merchantable bole was marked off in 7-foot sections from the butt, which was normally cut one foot above ground level. Cardinal directions were marked at each point previously designated for cross-cutting, then a disc 1-2 inches thick was cut out, labelled, and stored in a polyethylene bag to reduce moisture loss.

In the laboratory, each disc was marked with a 1-inch strip, from east to west and another from north to south, intersecting at the pith. Each strip was then marked into

1-inch lengths, labelled, then cut out with a small band saw.

### RESULTS

The green volume and oven-dry weight were then determined and the specific gravity calculated for each block, a total of 429 blocks from six trees. Individual block specific gravity varied from 0.36 to 0.65. Weighted<sup>3</sup> specific gravity of a radial strip varied from 0.38 to 0.61; disc specific gravity varied from a low of 0.40 to a high of 0.58.

Clearly there is variation; the problem is to determine the pattern.

### TREE SPECIFIC GRAVITY

The question of most interest was whether tree specific gravity could be estimated from a small sample. Affirmative results have been obtained with pine (Harris 1963, Zobel & Rhodes 1956), and for other characteristics with poplar (B'alobok 1963), fir (Stage 1963), and spruce (Ruden 1963), among others (Zobel 1961). The small sample of greatest utility in a program of tree improvement would be the first wood laid down. Therefore, a regression was run of specific gravity of the tree on that of the core at 1 foot height. That is, an equation  $Y = a + bx$  was solved, using the weighted specific gravity of the tree as "y" and the specific gravity of the 1-inch block from the center of the disc cut at 1-foot height as "x."

2/ The field procedure and preliminary analyses were conducted as part of a special study for the 1962 Syracuse Forestry Summer Course, conducted by New York State University College of Forestry at Syracuse, in cooperation with the U.S. Forest Service Institute of Tropical Forestry.

3/ Because a cube of fixed cross-sectional area represents a portion of the total which diminishes with distance from the pith, variable weighting must be used to determine radius or disc specific gravity. Area represented by a sample is approximately equal to  $\pi$  times the square of the radial distance to its outer limit, minus  $\pi$  times the square of the radial distance to its inner limit. This yields areas of 0.785, 6.281, 12.566, 18.850, and 25.172 square inches for 1-inch squares with the radial length to the outer edge of 0.5, 1.5, 2.5, 3.5, and 4.5 inches, respectively. Dividing through by 0.785 gives relative weights of 1, 8, 16, 24, 32, 40, 48, 56, etc.

In other words, the ring of wood 5.6 to 6.5 inches from the pith has 48 times as much cross-sectional area as a ring from 0.1 to 0.5 inch from the pith.

The mean specific gravity of a radial strip, therefore, equals 1 x specific gravity at 0-0.5 inch from the pith, plus 8 x specific gravity at 0.6-1.5 inches, plus 16 x specific gravity at 1.6-2.5 inches . . . , plus 48 x specific gravity at 5.6-6.5 inches, the sum of the products being divided by the sum of the weightings.

The relationship was encouraging, a correlation coefficient of 0.618, but was not significant for so few trees.

When the equation was expanded to include growth rate (as expressed by dbh), the correlation was raised to significance. Further expansion of the equation to include merchantable height raised the combined correlation coefficient to 0.987. Best estimate of the tree specific gravity was:

$$\begin{aligned} \text{Tree Specific Gravity} = & 0.1834 + 0.4790 \\ & \text{Core Specific Gravity at 1 foot} \\ & + 0.01649 \text{ dbh} - 0.01124 \text{ No.} \\ & \text{7-foot Bolts.} \end{aligned}$$

#### GROWTH RATE

Since the importance of growth rate was so clearly indicated in the preceding analysis, two further tests were made.

The first was to determine whether the specific gravity of the wood most recently laid down was also correlated with growth rate. Considering only the outermost 1-inch blocks at the 1-foot and 8-foot levels, their specific gravity had a correlation coefficient of 0.91 for dbh alone, and 0.94 for dbh and height in combination.

The next test was to determine whether the specific gravity of a particular radius, as compared to the entire cross-section of the stem, was related to the length of radius, as compared to the average radius for that cross-section. If

$$\text{"y"} = \frac{\text{Radius Specific Gravity}}{\text{Disc Specific Gravity}}$$

$$\text{and "x"} = \frac{\text{Radius Length}}{\text{Disc Average Radius}}$$

is y correlated with x, in the equation  $Y = a + bx$ ? For the 136 discs available for analysis, there was virtually no correlation whatever.

The two preceding analyses indicate then, that (a) tree specific gravity increases with

tree growth rate as expressed by dbh and number of bolts, but (b) specific gravity along a radius within a particular cross-sectional disc of the bole is not related to the relative growth rate along that radius.

That is, specific gravity increased with increasing tree growth rate, but did not vary with variations in growth rate along different radii at the same level in the same tree.

#### CORE VERSUS ADJACENT BLOCKS

As noted above, some reports (Grossler 1943, Nylander 1953, Sekhar & Negi 1961) have indicated that the wood immediately surrounding the pith is relatively heavy, and that the very light "juvenile" wood does not include the actual tree center.

Comparison indicated that in these 34 mahogany discs the core is highly significantly lighter than the adjoining blocks. Practically speaking, however, the difference of 2 percent is of little consequence.

#### VARIATION ABOUT THE BOLE

To determine whether specific gravity varies around the bole at a given level, the four radial values obtained were placed in descending order. The results are exemplified in Table 1.

Table 1. *Mean specific gravity at specified heights of peripheral blocks, all trees combined. For each tree the values were placed in order of magnitude.*

| Height  | Specific Gravity |                |               |        |      |
|---------|------------------|----------------|---------------|--------|------|
|         | Highest          | Second Highest | Third Highest | Lowest | Mean |
| Feet    |                  |                |               |        |      |
| 1       | .533             | .523           | .517          | .498   | .518 |
| 8       | .457             | .443           | .438          | .427   | .441 |
| 15      | .470             | .448           | .438          | .428   | .446 |
| 22      | .496             | .474           | .460          | .448   | .470 |
| Average | .489             | .472           | .463          | .450   |      |

The apparent differences are highly significant, but this could be random variation. There have been many reports that specific gravity differs on the north and south sides of the stem (Nylinder 1953).

Table 2. *Mean specific gravity of mahogany, by height above ground and cardinal direction. Individual blocks were weighted by distance from the pith; each tree value was given unit weight.*

| Height<br>above ground<br>feet | Specific Gravity by Cardinal Direction |       |      |      | Entire<br>Disc | No.<br>Trees |
|--------------------------------|----------------------------------------|-------|------|------|----------------|--------------|
|                                | North                                  | South | East | West |                |              |
| 1                              | .52                                    | .51   | .51  | .50  | .51            | 6            |
| 8                              | .44                                    | .44   | .43  | .44  | .44            | 6            |
| 15                             | .45                                    | .44   | .45  | .45  | .45            | 5            |
| 22                             | .47                                    | .47   | .46  | .50  | .48            | 5            |
| 29                             | .49                                    | .49   | .47  | .51  | .49            | 5            |
| 36                             | .52                                    | .51   | .52  | .55  | .53            | 3            |
| 43                             | .58                                    | .57   | .56  | .55  | .56            | 2            |
| 50                             | .52                                    | .52   | .54  | .54  | .53            | 2            |
| Total Stem                     | .49                                    | .48   | .48  | .49  | .486           |              |

Inspection of Table 2 shows that for the stem as a whole no significant differences are to be found between directions. There are indications that two borings give a more accurate estimate than one, and that borings 180° apart may give a more accurate estimate than those 90° apart.

The data presented by Lenz (1954) showed this same overall uniformity among radii, but showed rather clear differences at some point up the bole. The same indication is found in Table 2; in this case, the west radius appears heaviest in the neighborhood of 25 feet.

#### VARIATION ALONG THE BOLE

Both tables 1 and 2 clearly show that specific gravity is high at the base, drops to a minimum at eight feet (of the heights tested), then climbs steadily to near the base of the crown.

#### VARIATION ALONG THE RADIUS

The variation in length between radii prevents a clear tabular presentation of the variation of specific gravity outward from the pith.

The combined indications mentioned in the three preceding sections were tested by multiple regression analyses<sup>4/</sup>.

Specific gravity of the west radius is significantly heavier, at heights of 22 and 29 feet. It must be emphasized that an analysis such as this proves only that a difference the authors thought they saw in a particular set of data actually exists. Only further testing can indicate whether the relationship found in these trees is part of a general pattern.

Specific gravity varied significantly with height in bole. Each tree showed the same

4/ The authors are indebted to the Computing Laboratory, Oxford University for machine solution of a number of the equations.

trend, and there seems little room for doubt that the sample represents a real pattern. Variation is much more strongly correlated with absolute height than with relative height; that is, height in feet was a better expression than height as a percentage of merchantable height.

Specific gravity also increased significantly outward along a radius. Inches from the pith was a more useful expression than percentage of the total radius.

### CONCLUSIONS

A study was made of the variation of specific gravity in the boles of six plantation-grown trees of bigleaf mahogany.

1. Tree specific gravity can be estimated from specific gravity at the core of a disc cut one foot above the ground line,  $r = 0.618$ .

2. A highly significant correlation was obtained of tree specific gravity with the combination of core-at-1-foot specific gravity plus dbh plus merchantable height,  $r = 0.987$ .

3. The specific gravity of the outer 1-inch of wood in the lower bole was correlated with the same three variables. The correlation coefficient was identical to three decimals 0.987, but there was relatively less correlation of the outer wood with core specific gravity and more with dbh.

4. The variation in specific gravity of radii at a given height of a particular tree was not related to their relative growth rates at that point.

5. The wood immediately surrounding the pith was the lightest, and specific gravity increased outward. Progression was erratic or altogether missing in some radii.

Specific gravity was high at the base, dropped to a minimum at eight feet, then increased upwards to near the base of the crown.

7. For the entire trees, specific gravity varied between radii, but not in a definite pattern.

8. At a height of 22 and 29 feet wood in these six trees averaged significantly heavier on the west radius.

9. Position along the radius removed more of the total variance when expressed in inches from the pith than when expressed as a percentage of the radius.

10. Height in feet removed more of the total variance than did height as a percentage of merchantable height.

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