THE EFFECT OF RAY TISSUE ON THE SPECIFIC GRAVITY OF WOOD

Fred W. Taylor

Mississippi Forest Products Utilization Laboratory,
P.O. Drawer FP, State College, Mississippi 39762

ABSTRACT

Rays, important tissues in all woods, may comprise as much as one-third of the total xylem of some species. This fraction of the wood, composed mostly of short parenchyma cells, is of little advantage in the use of wood except to enhance the appearance of decorative wood. A method of estimating the specific gravity of rays from measurements on the relative amount of cell wall substance is described, and estimated specific gravities are reported for the rays of several species.

The most significant report is that rays have a higher specific gravity than the surrounding wood composed of all the various woody tissues. The conclusion drawn from this observation is that increased ray volume may contribute to increased specific gravity. Hence, selection for high specific gravity may result in selection for high ray volume, which would most probably be undesirable.

Rays have been largely ignored as either individual xylem elements or as a tissue by both wood technologists and forest geneticists in recent years. Such a lack of interest is surprising in view of the fact that one-fourth to one-third of the total xylem of some species is composed of this tissue (Myer 1922; Chalk 1955; Huber and Prütz 1938). When the magnitude of wood volume composed of rays is considered from the viewpoints: 1) that ray cells are short in length and thus less valuable than longitudinal prosenchyma cells for papermaking; 2) that the proportion of ray tissue in wood is positively correlated with hardness, modulus of rupture, and compression perpendicular to the grain (Myer 1922) and 3) that rays are an important factor in the anisotropy of wood (Clarke 1930; Greenhill 1949; McIntosh 1954; Schniewind 1959; Kennedy 1968); it is obvious that variations in the volume of this tissue are quite important.

Ray parenchyma cells, as seen in microscopic observation of wood sections and macerated material, are thin-walled cells which would appear to detract from the specific gravity of wood. Yet species characterized by high specific gravity frequently contain large amounts of ray tissue. The objective of this research was to measure the specific gravity of ray tissue and to investigate the influence of rays on total wood specific gravity.

BACKGROUND

Reported research on variation of the volume, number, and dimensions of rays indicates a pattern quite similar to that reported for the better-known wood properties. Ray volume is at a maximum in the root and stem base, maintains a consistently lower volume in the bole, and increases to a second maximum in the upper portion of the crown (De Smidt 1922; Harlow 1927). The greatest number of rays is also found at stump level with a decrease at higher points in the stem to the height where an increase in number again begins and continues into the crown (Goggans 1961). It should be noted at this point that increases in the number of rays are not necessarily associated with increases in ray volume (Harlow 1927).

At a given height, the number of rays per unit area is largest in the first annual ring. This number decreases (at first rapidly and then more slowly) with distance from the pith until it becomes constant throughout a zone which varies with different trees. Beyond this constant zone, the number of rays again increases in rings put on after the "maturity" of the tree (Weinstein 1926). Growth rate was suggested by

Bannan (1937, 1954) as a factor affecting rays. He reported that as ring width increased in conifers, the number of rays per unit area decreased while their volume increased. However, extreme growth conditions were reported to have no effect on ray volume for various poplar clones (Schulz 1962).

Variations found in the ray volume of many wood species led Myer (1922) to conclude that the larger variations were due to inheritance and the smaller variations to differences in environment. The importance of genetic control over ray volume and over other characteristics of rays was restated more recently by Goggans (1961).

RESEARCH PROCEDURE

The research procedure was basically one of measuring the amount of cell wall substance in ray tissue and using this value to estimate the specific gravity of rays. Specific gravity was estimated by the equation:

$$\text{Specific Gravity} = 1.07W,$$

where W represents the percentage of the ray occupied by cell wall material, and the constant 1.07 is the approximate specific gravity of swollen wood substance.

The measurement technique employed a "Lietz integrating eyepiece" for making and accumulating measurements. The technique consisted of superimposing transect lines on rays as viewed on tangential wood sections and recording the percentage of the lines that traversed cell walls. The lines were located obliquely to the height axis of rays. Measurements were made at a magnification of 500×.

Species investigated were: yellow-poplar (*Liriodendron tulipifera* L.), beech (*Fagus grandifolia* Ehrh.), red oak (subgenus *Erythrobalanus*), and white oak (subgenus *Leucobalanus*). Yellow-poplar was chosen because samples were available from trees of known wood properties.

Three rays located on one sample block (1 × 1 × 2 cm) from each of six yellow-poplar trees were measured. Blocks from the fifteenth growth ring at breast height were measured for each tree. Six transects, separated by 0.0367 mm, were superimposed diagonally on each ray.

Cell wall measurements of the other study species were made on sample blocks picked at random from wood collection bins. For these species, three rays from each sample block (approximately 1 × 1 × 2 cm) were measured. Because of the great width and height of rays in these species, the number of measurement transects varied. However, the total lengths of the transect lines were approximately equal for the measurement of each ray (4.1 mm).

After the microscopic measurements were complete, gross specific gravity (green volume basis) was determined for each sample block.

RESULTS

Yellow-Poplar

Ray specific gravity estimates, based on the observed proportion of cell-wall substances, are reported in Table 1. The average specific gravity of rays (0.58) was considerably higher than the specific gravity (0.41) of the sample blocks containing the rays.

Microscopic observation revealed that rays were compact tissues. Individual cells were of configurations that permitted almost perfect contact with adjacent cells. Hence, intercellular spaces were seldom observed, and cell walls were frequently quite thick at points where several cells made contact at a common point. No structures similar to vessels, which composed 43% of the tissue in the six study trees (Taylor 1968a), were present in rays. This absence of large internal cell voids and the near absence of intercellular spaces probably explain the relatively high specific gravity of ray tissue.

The foregoing explanation should not be construed to mean that ray parenchyma has thicker walls or contributes more to the specific gravity of yellow-poplar than the fiber tracheids. It does mean that increases in the proportion of either ray tissue or fiber tracheids tend to increase the total wood specific gravity.

Considerable variation in estimated spe-

TABLE 1. *Specific gravity of wood rays in yellow-poplar, estimated from the amount of cell wall substance observed in ray transects*

Tree Number	Ray Number	Transect Number 1	2	3	4	5	6	Ray Average	Tree Average
1	1	.63	.62	.68	.48	.51	.50	.57	.60
	2	.69	.63	.69	.55	.50	.54	.60	
	3	.73	.57	.64	.57	.63	.73	.63	
2	1	.86	.72	.67	.69	.66	.65	.70	.62
	2	.46	.60	.62	.44	.49	.78	.56	
	3	.70	.67	.60	.59	.41	.57	.59	
3	1	.47	.48	.78	.48	.63	.52	.56	.57
	2	.64	.66	.48	.67	.48	.56	.57	
	3	.77	.56	.53	.58	.49	.54	.57	
4	1	.50	.57	.52	.58	.50	.46	.52	.56
	2	.59	.53	.60	.51	.63	.62	.58	
	3	.68	.60	.56	.52	.56	.64	.59	
5	1	.54	.60	.62	.60	.63	.67	.60	.58
	2	.64	.49	.56	.51	.62	.63	.58	
	3	.52	.61	.53	.63	.69	.39	.57	
6	1	.53	.61	.38	.87	.56	.49	.57	.60
	2	.63	.57	.61	.51	.62	.61	.60	
	3	.63	.67	.59	.57	.72	.58	.62	

cific gravity was observed among rays in each tree and among transects of individual rays. Hence, analysis of variance showed no significant differences in specific gravity among trees or among rays within trees. An interesting observation, however, is that the lowest ray specific gravities were recorded for those sample blocks with the lowest gross specific gravity. Specific gravity of sample blocks for trees one through six were respectively: .43, .41, .36, .36, .43, .44. This suggests that when low specific gravity wood is being formed, primarily because of thinner-walled prosenchyma (Taylor 1968b), the wall thickness of ray cells is also reduced. Further study is necessary for an understanding of the variation of wall thickness in ray tissue.

Broad-Ray Species

In each of the three broad-ray species investigated, the ray tissue was higher in specific gravity than was the entire sample

TABLE 2. *Specific gravity of wood rays, estimated from the amount of cell wall substance observed in ray transects*

Species	Ray Number	Transect Number 1	2	3	4	5	6	Ray Average	Species Average
White oak	1	.60	.60	.61	—	—	—	.63	.64
	2	.66	.62	.64	.64	.62	—	.63	
	3	.64	.66	.67	—	—	—	.66	
Red oak	1	.68	.66	.72	.66	.69	—	.68	.69
	2	.70	.73	.69	.68	.66	—	.69	
	3	.69	.70	.70	.75	.73	—	.71	
Beech	1	.76	.74	.78	.74	.73	.70	.74	.76
	2	.80	.81	.78	.71	.73	—	.77	
	3	.76	.78	.80	.78	.76	—	.78	

block upon which ray measurements were made. Comparable values were:

Species	*Total Tissue Sg.*	*Ray Sg.*
White Oak	.63	.64
Red Oak	.61	.69
Beech	.58	.76

The most pronounced difference was in beech where ray tissue was considerably more dense than the entire wood tissue. The ray cells of this species were very thick walled and tightly packed. Specific gravity values for individual rays and transects are reported in Table 2.

DISCUSSION

The relationship between rays and total xylem specific gravity is of immediate practical importance to tree breeders. Most tree improvement programs use specific gravity as a criterion for selection, yet few breeders evaluate the ray volume of their selections. It is conceivable that selection for high specific gravity *per se* may result in increased ray volume in the selected material. Increased ray content is, of course, undesirable for most present uses for wood. Hence, the tree breeder should be aware of the relationship between ray volume and specific gravity, and should occasionally evaluate ray volume and other anatomical characteristics such as vessel volume, fiber wall thickness, and parenchyma content which are responsible for variations in specific gravity.

REFERENCES

BANNAN, M. W. 1937. Observations on the distribution of xylem-ray tissue in conifers. Ann. Bot. (London) L: 717–726.

———. 1954. Ring width, tracheid size, and ray volume in stem wood of Thuja occidentalis. Can. J. Bot. **32**(3): 466–479.

CHALK, L. 1955. Ray volumes in hardwoods. Tropical Woods **101**: 1–10.

CLARKE, S. H. 1930. The differential shrinkage of wood. Forestry **2**: 93–104.

DESMIDT, W. J. 1922. Studies in the distribution and volume of the wood rays of slippery elm. J. Forest. **20**: 352–362.

GOGGANS, JAMES F. 1961. The interplay of environment and heredity as factors controlling wood properties in conifers with special emphasis on their effects on specific gravity. Tech. Rept. No. 11, School of Forestry, North Carolina State University at Raleigh.

GREENHILL, W. L. 1949. The differential shrinkage of wood. Trans. A.S.M.E.: **66**: 2: 152–154.

HARLOW, W. H. 1927. The effect of site on structure and growth of white cedar (*Thuja occidentalis*). Ecology **8**: 453–470.

HUBER, BRUNO AND GERHARD PRÜTZ. 1938. Über den Anteil von Fasern, Gefassen und parenchym am Authau verschiedener Hölzer. Holz als Roh- und Werksstoff **10**: 373–381.

KENNEDY, R. W. 1968. Wood in transverse compression. Forest Prod. J. **18**(3): 36–40.

McIntosh, D. C. 1954. Some aspects of the influence of rays on the shrinkage of wood. Forest Prod. J. **4**: 1.

MYER, J. E. 1922. Ray volumes of the commercial woods of the United States and their significance. J. Forest. **20**: 337–351.

SCHNIEWIND, A. P. 1959. Transverse anisotropy of wood a function of gross anatomic structure. Forest Prod. J. **9**(10): 350–359.

SCHULZ, H. 1962. On the effect of extreme growth conditions on the wood of various poplar clones. Holz als Roh- und Werkstoff **20**(9): 347–357.

TAYLOR, F. W. 1968a. Variations in the size and proportions of wood elements in yellow-poplar. Wood Sci. and Tech. **3**(2): 153–165.

———. 1968b. Specific gravity differences within and among yellow-poplar trees. Forest Prod. J. **18**(3): 75–81.

WEINSTEIN, A. L. 1926. Summary of literature relating to volume, distribution, and effects of medullary rays in wood. J. Forest. **24**: 915–925.