RESEARCH BULLETIN 912 MARCH 1967

UNIVERSITY OF MISSOURI COLLEGE OF AGRICULTURE

AGRICULTURAL EXPERIMENT STATION

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Growth-Quality Evaluation of Black and Scarlet Oak Grown in Missouri

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(Publication authorized March 17, 1967)

COLUMBIA, MISSOURI

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ACKNOWLEDGEMENTS

The authors wish to thank the Cloud Oak Flooring Company of Springfield, Missouri, for providing sample material used in this study. Samples were obtained from company mills at Vienna and Winona, Mo.

This bulletin is a report on studies of growth-quality relationships of various commercial timber species of Missouri. The work was undertaken as a part of Project 535, supported primarily by McIntire-Stennis funds, of the School of Forestry and covers a portion of investigations underway on several hardwood species important to the wood-using industries of the state. The U.S. Forest Service provided both financial and technical assistance.

Growth-Quality Evaluation of Black and Scarlet Oak Grown in Missouri

E. A. McGinnes, Jr.,[1] and R. A. Ralston[2]

INTRODUCTION

The bulk of Missouri's commercial forest is composed of hardwood species with the oak-hickory type dominating. Some 34 species and hybrids of oak occur in Missouri (15). Black (*Quercus velutina,* Lamark) and scarlet (*Quercus coccinea,* Muench) oaks comprise 30-35 percent of timber resources of the heavily forested eastern Ozark region.

This study was designed to obtain basic data on various indices (specific gravity, growth rate, etc.) of wood quality for utilization purposes. Data are presented in terms of age and growth-rate patterns (fast, slow, inconsistent, etc.) of xylem as measured from pith to bark on the small end of butt logs.

Sample analyses were designed to provide a rigorous test of the relationship between growth rate and specific gravity since the importance of growing trees under controlled growth-rate conditions has been questioned in recent years.

Growth rate, expressed in rings per inch or as actual width of annual increments, and specific gravity continue to be widely used indices of wood quality. Relative ease of measurement, small sample-size requirements, and good correlation with various properties of wood favor use of these indices.

Specific gravity and growth rate have been shown to be related to strength properties (5, 6, and 17) and machining characteristics (2, 3) of hardwoods. Pulp yield and qualities are also related to specific gravity; these relationships are well known and need not be covered here.

Growth rate, as an index of wood quality, has been used primarily as an indicator of specific gravity or wood density. Numerous investigations, particularly the recent ones, have indicated that growth rate and specific gravity are poorly correlated (1, 4, 5, and 7), with greater variation found in slow-growth material (5). Growth rate is related to specific gravity for ring porous woods, such as oak,

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in that fast growth is indicative of high specific gravity. Since it is easily measured, it will probably continue as a major index of wood quality.

Studies of the influence of environmental and hereditary factors upon wood quality of hardwoods have not been as numerous as those for coniferous species in the United States. This is perhaps because of greater utilization and, hence, of more economic importance of the latter species. Recent studies of various members of the red oak group have not indicated strong relationships between specific gravity and certain environmental conditions such as site and soil (4, 12). Current thinking, at least as applied to coniferous species, is that both environmental and genetical modifications should be employed to improve wood properties (8).

Unlike some coniferous species (southern yellow pines and eastern white pine) the oaks have a central core of relatively high density wood adjacent to the pith (4, 12). Fiber length increases from pith to bark for various oak species (5, 14). Porosity of oak has been shown to vary with height within the tree (13). The foregoing studies indicate considerable variation of properties within the merchantable bole, a situation receiving increased attention in growth-quality research efforts today.

METHODS

The sampling technique was designed to determine the influence of various growth-rate patterns upon quality indices for black and scarlet oak harvested at rotation ages of 90 years and 70 years, respectively (14). Five growth-rate patterns, from pith to bark were selected. These covered the probable classes of growth rate (see Figure 1).

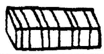
SPECIES	UNIFORM GROWTH RATE		NON-UNIFORM GROWTH RATE		
	FAST 	SLOW 	FAST → SLOW 	SLOW → FAST 	INCONSISTENT 
BLACK OAK	3	3	3	3	3
SCARLET OAK	3	3	2	2	3

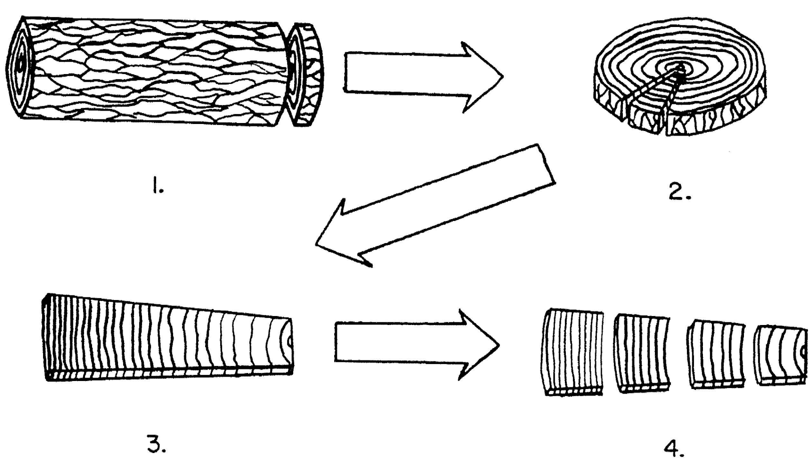
Fig. 1—Method of sampling for five growth-rate patterns from pith to bark for 94-year-old black and 67-year-old scarlet oak trees. Numbers in blocks indicate number of trees sampled.

As shown in Figure 1, two types of uniform growth rate were selected: (1) fast throughout the life of the tree and (2) slow throughout the life of the tree. Three classes of non-uniform growth-rate were also sampled: (1) initial fast growth followed by slow growth as measured from pith to bark, (2) initial slow growth followed by fast growth, and (3) an inconsistent growth pattern with three or more alternating cycles of either slow or fast growth.

Since both the age and growth-rate pattern of material to be sampled had to be known, cross-sectional disks from the top ends of butt logs were used for study. Increment core sampling of standing timber would be impractical under specified sampling conditions. The use of the top end of butt logs eliminated abnormal growth frequently associated with xylem tissue near ground level and permitted commercial utilization of the log. Butt logs sampled (15 black and 13 scarlet oak as shown in Figure 1) ranged in length from 10 to 14 feet.

Two sawmill yards were chosen as sites for obtaining sample material. Samples (disks) were removed immediately upon delivery of logs to the yard, making it possible to locate the approximate sites where the trees had grown.

The method of removing of the sample disk from a log and breaking the disk into samples suitable for laboratory analysis is shown in Figure 2. Starting



LEGEND

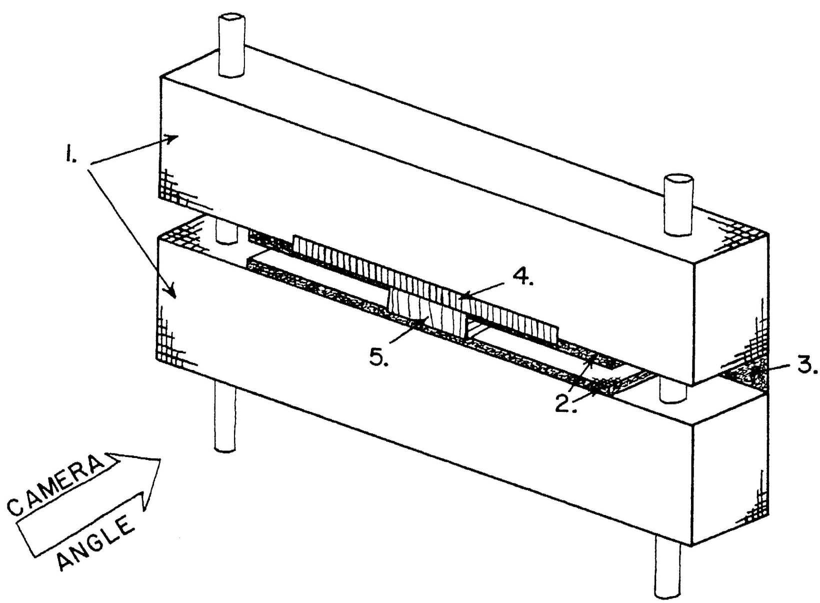
1. DISK REMOVED FROM TOP END OF BUTT LOG.
2. WEDGE REMOVED ALONG AVERAGE DISK RADIUS.
3. ONE OF SEVERAL SLICES CUT FROM WEDGE; SLICES DID NOT EXCEED 3/16" IN THICKNESS.
4. SLICE SEGREGATED INTO SAMPLES OF UNIFORM GROWTH RATE (EXCEPT PITH SECTION TAKEN AS FIRST 10 YEARS OF GROWTH).

Fig. 2—Diagrammatic sketch showing disk removal and subsequent disk breakdown into samples for analyses.

from the pith, the first within-disk sample prepared always terminated after the first ten-year period to provide a consistent analytical definition of juvenile (or crown-formed) wood. All remaining disk samples were prepared to include *only* a uniform growth rate (fast or slow). Maximum length of these sections ranged to two inches; longer uniform growth rate areas were broken into two or more parts. Original thickness along the grain was reduced by sanding to approximately ⅛″.

Recent investigations (7, 16) have shown that wood extractives have a significant influence on estimation of apparent specific gravity. Accordingly, samples were extracted in ethanol, ethanol-benzene, and water prior to determination of specific gravity using a maximum moisture content procedure (7).

Based on technique of Bethel (1) and Hamilton (4), ring width and percent springwood pore-area were obtained by measuring projections of 35-mm color slides. The apparatus for photographing wood samples is shown in Figure 3;



LEGEND

1. WOOD BLOCKS, (LOWER ONE STATIONARY, TOP ONE MOBILE).
2. BLACK SPONGE RUBBER CEMENTED TO WOOD BLOCKS.
3. BLACK PAPER BACKING (FASTENED TO UPPER BLOCK).
4. METRIC SCALE.
5. WOOD SAMPLE.

Fig. 3—Sketch of apparatus used for photographic recording of annual increment data. Wood samples were sanded to provide a relatively smooth surface.

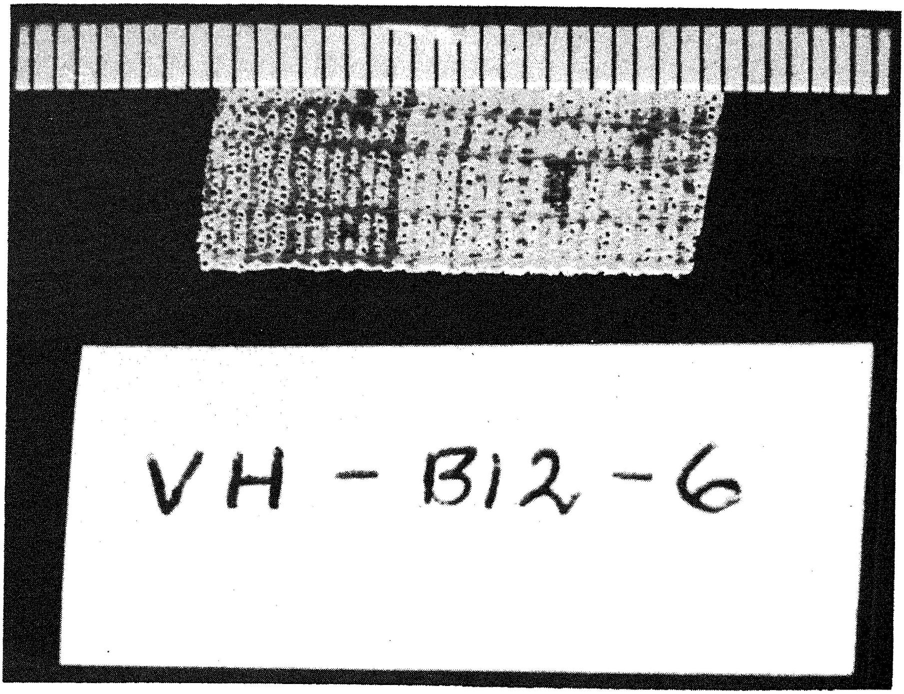


Fig. 4—Slow-growth black oak sample with millimeter scale plus sample number. 35-mm color slides of each wood sample investigated were similarly prepared.

Figure 4 shows a wood sample with identifying number recorded on the print.

One black oak and one scarlet oak, both from the all-fast-growth class, were selected for measurements of fiber length, fibril angle, cell wall thickness and cell width (Tangential plane).

For fiber length determinations samples were macerated (18) and microphotographs were taken at 22x. These were then projected and fiber length determined. Other fiber dimensions were obtained from direct measurement on radial or transverse microtome sections of wood. A Filar micrometer eyepiece was used for this work at magnifications ranging from 450x to 1000x.

Fibril angle measurements were estimated using a polarized light technique (7). Values obtained were compared with the angle of cell wall checks when the latter were present. No discrepency between these two methods of estimating fibril angle was found.

Ten trees were selected for determination of chlorite holocellulose (18) and Klason lignin. Extractives removable with ethanol, ethanol-benzene, and water were also determined on these samples. Disk segments used for chemical analyses were representative of the same age period and growth-rate class as those used for estimates of specific gravity, growth rate, and fiber dimensions. Lignin and holocellulose values are expressed on extractive-free, oven-dry basis. Holocellulose values were corrected for residual Klason lignin content.

RESULTS AND DISCUSSION

From a utilization standpoint, no distinction is made between the wood of black and scarlet oak (6); therefore data for total ring width, springwood pore zone width, and specific gravity have been combined in most aspects of this study. However, a comparison between black and scarlet oak for most indices measured is given in Table 1, primarily for academic interest although it should be remem-

TABLE 1--COMPARISON OF VARIOUS INDICES OF WOOD QUALITY FOR BLACK AND SCARLET OAK SAMPLES TAKEN FROM TOP END OF BUTT LOG

Statistic	Black Oak	Scarlet Oak
Average Age (years)	93	66
Growth Rate (mm/ring)	2.35[1]	2.83
Springwood Pore Zone Width (mm/ring)	0.93	1.06
Specific Gravity (green vol./wgt. O.D.)	.545[1]	.529[1]
Extractives-alcohol, alcohol-benzene,		
water - (%)	6.89	7.54
Klason Lignin[2] (%)	21.76	20.86
Chlorite Holocellulose[2] (%)	78.23	78.76
Fiber Length (mm)		
mature wood	1.63[3]	1.69[3]
juvenile wood	1.30[3]	1.32[3]
Fibril Angle (degrees)		
mature wood	2.5[3]	3.4[3]
juvenile wood	10.0[3]	15.2[3]

1 Difference between species significant at 5% level.

2 Values for five trees of each species and are expressed on an extractive-free basis.

3 Differences between species for same type (juvenile or mature) wood non-significant. Differences between (juvenile and mature) wood within species significant at 5% level.

bered that forest managers can control species composition to some extent.

For the trees sampled, the higher specific gravity for black oak with a slower average growth rate than scarlet oak is worthy of note. Since black oak also contained a larger average percentage of springwood pore-zone material, difference in specific gravity between the two species cannot be explained on this basis. It is possible that more detailed microscopic evaluation would reveal differences in fiber, parenchyma, or vessel wall thickness, which could account in part for the difference between species; however, such data are not presently available.

Limited data were obtained for estimates of specific gravity of individual annual increments and subdivisions thereof into springwood pore zones and summerwood fiber zones. Ten annual increments each of both black and scarlet oak mature wood were studied. The black oak samples were obtained from an inconsistent growth class tree; increments sampled were successive years from age 51-60. Scarlet oak samples were obtained from a tree of the same growth class as the black oak samples and increments studied were from age 41-50.

The range (.475 to .620) in specific gravity estimates for these 20 annual increments was of a magnitude comparable to that encountered for the data obtained on the larger samples (Figure 6). Isolated springwood pore zones ranged from .329 to .480 in specific gravity, and isolated summerwood zones ranged from .609 to .732. Results for estimation of springwood and summerwood specific gravities are comparable to those reported by Vikhrov (17).

The slight differences in lignin and holocellulose contents, either between species (Table 1) or age periods (Table 2), were not statistically significant. The results, however, are compatible with those of more extensive tests elsewhere (9).

Data for extractives content vs. age from the pith (Table 2) indicate a trend which is the opposite of that found in some coniferous species (7). The lower extractives content of the first 10-year period from the pith may be a result of several factors.

First, the difference in anatomical structure of this wood as compared to mature wood. In the early-formed juvenile wood, the springwood pore zone occupies a smaller percentage of total ring width as compared to mature wood (Figure 5). Also, the individual springwood pores are smaller in tangential diameter in this early-formed wood. This difference in both structure and amount of springwood pore zone material between juvenile and mature wood might indicate that the most readily removed extractive materials are located in springwood pore zones.

Second, it is possible that extractives are more readily removed from either springwood pore areas or from the mature wood zones as a whole. To test this, samples of both juvenile and mature wood zones were ground in a Wiley mill and analyzed separately for extractives content. The data from the analyses were then compared with similar data from unground wood sections. Although the amount of extractable material removed from the finely ground wood samples was slightly higher than that for unground wood samples, the *trend* remained

TABLE 2--EXTRACTIVES, LIGNIN AND HOLOCELLULOSE CONTENTS FOR BLACK AND SCARLET OAK SAMPLES AT VARIOUS AGE PERIODS FROM THE PITH. SAMPLES TAKEN FROM TOP END OF BUTT LOG

Age Period (Years from pith)		Extractives (Percent)		Lignin[1] (Percent)		Holocellulose[1] (Percent)	
Black	Scarlet	Black	Scarlet	Black	Scarlet	Black	Scarlet
10	10	5.08	3.62	21.53	21.43	77.94	77.65
26	24	8.36	6.73	21.30	21.07	78.06	77.62
39	35	7.75	8.64	21.32	21.05	77.32	79.24
--	46	----	7.68	-----	21.04	-----	80.26
53	53	7.68	6.74	21.08	20.59	78.94	78.88
--	61	----	7.50	-----	21.01	-----	79.66
67	66	8.20	7.79	21.35	-----	78.27	79.65
83	--	7.28	----	22.00	-----	78.07	-----
93	--	6.81	----	23.79	-----	77.12	-----

[1] Values expressed as percentage of extractive-free wood. Holocellulose values corrected for residual lignin content (ranged from 0.87% - 2.56%).

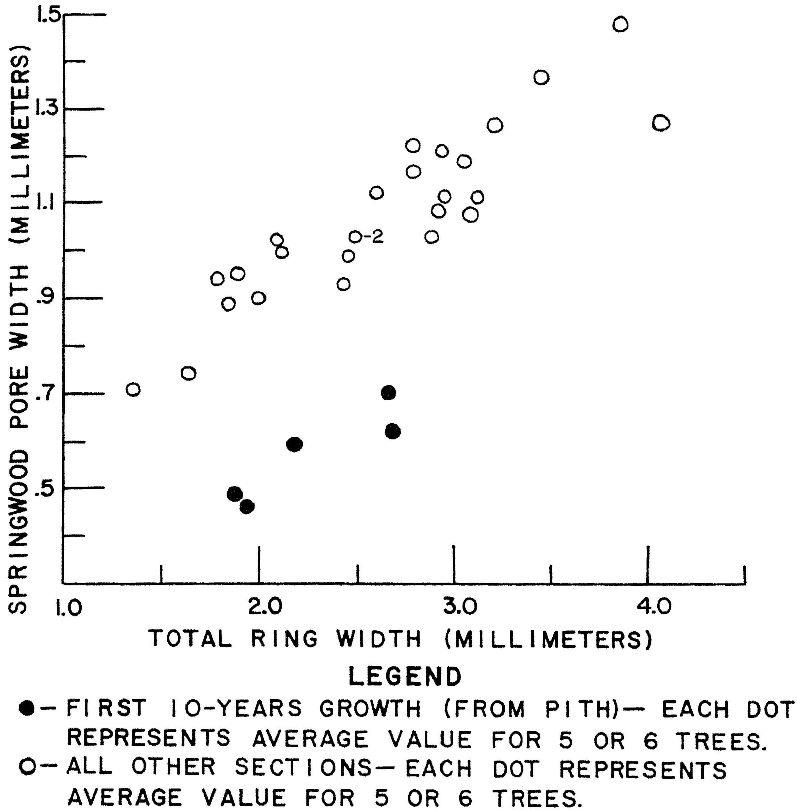


Fig. 5—Relation of springwood pore zone width to total ring width. Species combined.

unchanged; i.e., the juvenile wood zone contained the lower amount of extractive material regardless of method of analysis. There are, of course, other possibilities that may attribute to the noted difference in extractive contents between juvenile and mature regions of growth.

Relationships of ring width, percent springwood pore zone, and specific gravity to age from the pith are presented in Figure 6. No distinction between species is made in these data presentations.

Specific gravity was poorly correlated with growth rate (r = .319) and age from pith (r = -.407); however, specific gravity was strongly correlated with percent springwood pore-zone material (r = -.779). The multiple correlation (R) for these indices was .799. The negative relationship between specific gravity and age from the pith substantiates the findings of other investigators on red oaks.

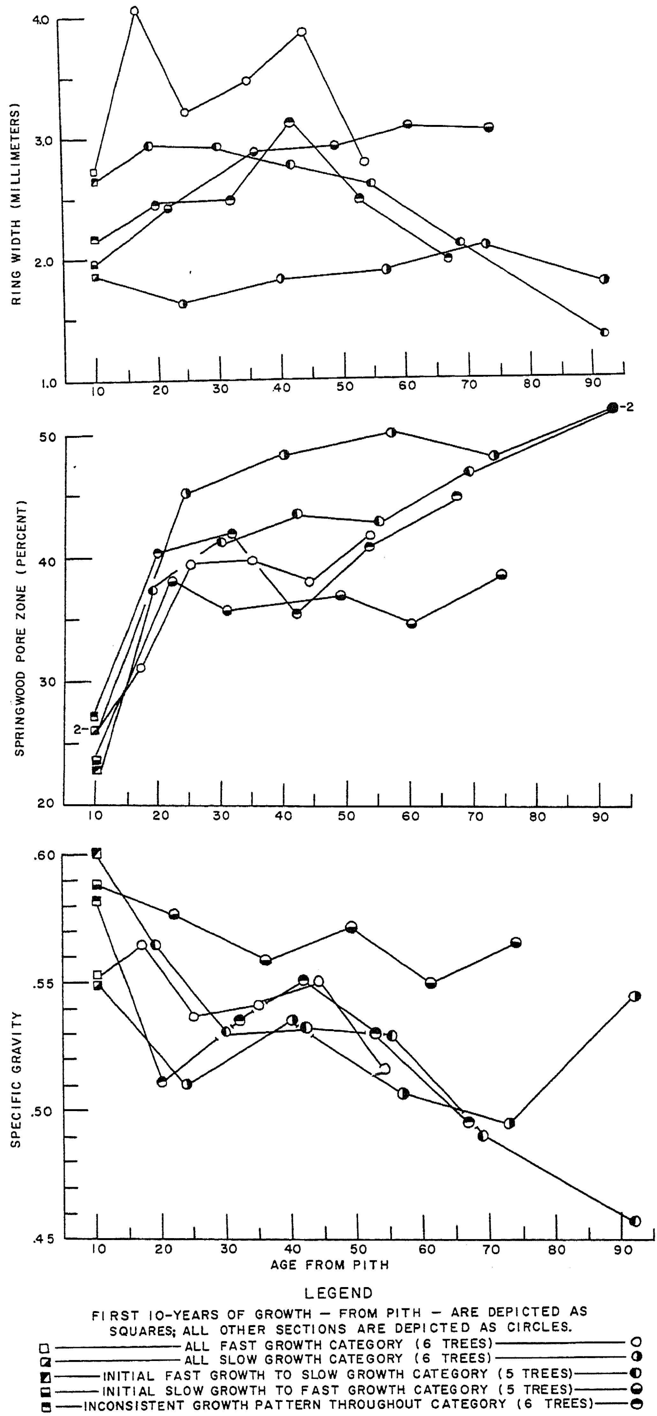


Fig. 6—Relation to total ring width, percent springwood pore zone, and specific gravity to age from pith. Species combined.

With reference to the distinct difference between total ring width and percent springwood pore-zone material for juvenile vs. mature wood (Figure 5), observations made on several transverse sections of juvenile wood were: (1) that neither growth rate nor species had any effect on the time in years required for tansition from juvenile to mature wood characteristics, and (2) that in general, after the seventh year from the pith, the wood appeared similar in structure to that formed subsequently.

The relationship between percent springwood pore zone material and age from the pith for the five growth-rate categories (Figure 6) was as anticipated for the all-slow-growth category. However, trees with initial slow followed by fast growth had the lowest average percent springwood pore zone material of any growth class. Trees of the all-fast-growth-throughout-life category were intermediate in this respect.

Regardless of growth class pattern, specific gravity was highest for the first ten years of growth (Figure 6), and with the exception of trees in the initial fast-growth followed by slow-growth category, specific gravity decreased up to 75 years. For classes with older trees, the specific gravity of the all-slow growth class trees increased from .50 to .55 from ages 73 to 93. On the other hand, trees in the fast-to-slow growth class decreased in specific gravity from .48 to .46 from ages 70 to 93. The percent springwood pore zone material at age 93 for these two growth patterns was the same. Wide variation in specific gravity for slow growth oak has been reported previously (5).

Since specific gravity values ranged from .495 to .570 over the first 70 years of growth (Figure 6), the rate of growth did not appear to have much influence on wood quality (as indicated by specific gravity) for trees sampled in this study. After age 70, the relationship between specific gravity and growth rate for slower growing trees was even more variable.

Fibril angle and fiber length data (Table 1) indicated a similar trend to that found in coniferous species; i.e., the shorter fibers and the fibers with a larger fibril angle were in the juvenile wood zone as compared to fibers found in older, mature wood. The magnitude of differences for fiber length or fibril angle between juvenile and mature wood is not as great as is encountered in most coniferous species.

Because of the diverse types of growth-rate patterns sampled which, upon analyses, did not indicate a strong relationship between rate of growth and specific gravity, it is suggested that emphasis in future research should be placed on genetic makeup as well as environmental control. This suggestion is based on the continued use of specific gravity as an important index of wood quality.

SUMMARY

Fifteen 90-year-old black and thirteen 70-year-old scarlet oak butt logs were selected for measurement of certain wood quality indicies. Sampling was designed to include five different diameter growth-rate patterns as measured from pith to bark on the small end of logs.

Disks cut from the small ends of logs were used for laboratory analyses. With the exception of juvenile wood defined as the first 10 years from the pith, disks were divided into samples of uniform growth-rate. Indices of wood quality measured were: specific gravity, percent springwood pore zone material, growth rate, and percent extractive materials for all samples. Five logs (one for each growth-rate class) of each species were selected for analyses of lignin and holocellulose. One log of each species was used for measurement of fiber dimensions and fibril angle.

Analyses of data showed that:

1. Maximum moisture content procedures for estimation of specific gravity were satisfactory when samples had been previously extracted (alcohol, alcohol-benzene, water) to remove extraneous materials.

2. The juvenile (or crown-formed) wood was higher in specific gravity, contained less extractive material, and had shorter fibers than wood formed subsequently.

3. Percent lignin and holocellulose remained fairly constant from pith to bark; extractives' content was lower for the first 10 years of growh than for the remainder of the xylem. Extractive content was reasonably constant for all sections of the xylem except in juvenile wood.

4. Specific gravity of black oak samples was found to be signficantly higher than scarlet oak samples (.545 vs. .529, respectively).

5. Overall correlations between specific gravity and growth rate, age from pith, and springwood pore zone percentage were .319, -.407, and -.779, respectively. The multiple correlation (R) for these parameters was .799. As disk subdivision was on the basis of uniform growth rate (except for juvenile wood), the correlation established in this study between specific gravity and growth rate is based on more rigid control of growth rate variation (within individual samples) than is possible by conventional methods of analyses on wood samples of either constant length or definite age periods. Thus, the significant, though low correlation established between specific gravity and growth rate indicates that the control of growth rate for purposes of producing wood of high density is not important. For all practical purposes, trees should be grown as fast as economically feasible in Missouri.

6. Samples from the slow-fast growth category had the highest average specific gravity (.568); whereas samples in the all-slow-growth class had the lowest average specific gravity (.522).

LITERATURE CITED

1. Bethel, J. S. Factors influencing the specific gravity of chestnut-oakwood. Journal of Forestry (41):599-601. 1943.
2. Davis, E. M. Texture of southern hardwoods and locality of growth. Southern Lumberman 147(1865):69-70. 1933.
3. Davis, E. M. Machining and Related Characteristics of Southern Hardwoods. United States Department of Agriculture Technical Bulletin 824. 42 pp. 1942.
4. Hamilton, J. R. Certain wood properties of southern red oak *(Quercus falcata)* in relation to location within the bole and to environment. Thesis. North Carolina State College. 243 pp. 1960.
5. Khursudjan, I. A. (Some data on evaluation between annual ring width and the physical and mechanical properties of the wood of Armenien oaks.) U.S.S.R. (Biol. —Hoz. Nauki.) 11(4):33-43. 1958.
6. Markwardt, L. J. and T. R. C. Wilson. Strength and related properties of wood grown in the United States. United States Department of Agriculture Technical Bulletin 479. 99 pp. 1935.
7. McGinnes, Jr., E. A. Growth-Quality Evaluation of Missouri-grown Shortleaf Pine (*Pinus echinata,* Mill). University of Missouri, Agricultural Experiment Station Research Bulletin 841. 59 pp. 1963.
8. Mergen, F., J. Burley, and C. W. Yeatman. Variation in growth characteristics and wood properties of Norway spruce. TAPPI 47(8):499-503. 1964.
9. Nikitin, N. I., Rudneva, T. L., Caitseva, A. F. and M. M. Chovieva. (Study of the chemical composition of oakwood as influenced by type of forest). Transl. For. Prod. Aust. 14 pp. 1949.
10. Paul, B. H., and R. O. Marts. Growth, specific gravity, and shrinkage of twelve Delta Hardwoods. Journal of Forestry 32:851-873. 1934.
11. Paul, B. H. Variation in the porosity of twelve species of oak. Southern Lumberman (64):31-33. 1942.
12. Paul, B. H. Second growth oak. Part I. Part II. Southern Lumber Journal and Building Materials Dealer. Part I. 4 pp. January 1959. Part II. 3 pp. February 1959.
13. Savina, A. V. (The physiological justification for the thinning of forests.) Goslesbumicdat, Moscow and Leningrad, 1956. National Science Foundation Translation. Office Technical Service No. 60-51130. 91 pp. 1960.
14. Schirck, R. A. and L. L. Sluzalis. Timber Management Guides for the Missouri National Forest. Unpublished Report. 34 pp. 1959.
15. Settergren, C. D. and R. E. McDermott. Trees of Missouri. School of Forestry. University of Missouri. Agricultural Experiment Station Bulletin 767. 123 pp. 1962.
16. Thor, E. Variation in Virginia pine. Part I: Natural Variation in Wood Properties. Journal of Forestry (62): 258-262. 1964.
17. Vikhrov, V. E. (The structure and physiomechanical properties of oak spring- and summer-wood.) Trudy Ins. Lesa. (Akad. Nauk, U.S.S.R.). 9:29-38. 1953.
18. Wise, L. E., M. Murphy, and A. A. D'Addieco. Chlorite holocellulose, its fractionation and bearing on summative wood analysis and on studies on the hemicelluloses. Paper Trade Journal 122(2):11-19. 1946.