PATTERNS OF VARIATION IN FIBRIL ANGLES IN LOBLOLLY PINE

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PATTERNS OF VARIATION IN FIBRIL ANGLES IN LOBLOLLY PINE

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Angular orientation of fibrils to the length of summerwood fibers were determined for naturally seeded loblolly pines (*Pinus taeda* L.). Progress is reported on studies of basic anatomical features affecting properties of wood that are part of the comprehensive research program at the Forest Products Laboratory.

Some observations have shown that fibril orientation is widely variable in the secondary cell walls over a range from less than 5° to more than 25° in normal summerwood of yellow pines. The largest fibril angles tended to be associated with relatively wide annual rings and usually with the early rings formed in the trees.[2] The available information led to the hypothesis that variability in fibril angles was related to combinations of factors of position in successive rings (number) from the pith and, also, to conditions that affect vigor of growth such as are reflected by the width of annual rings.

The purpose of the present work was determination of sizes of fibril angles and patterns of their variations (1) in relation to width of the annual rings, (2) in successive rings (number) from the pith, and (3) at different heights with respect to the base of the active crown. Determinations of

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[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[2] Pillow, Maxon Y. Variability in Anatomical Features and Their Effects on Properties of Second-growth Yellow Pines. Forest Products Laboratory Report No. SR-21.

fibril angles were made for loblolly pines, 10 to 15 years old, that represented extremes in spacing; namely, thicket-grown and open-grown trees and also ones that had been released from overtopping hardwoods. Determinations also were made for other trees, 30 to 35 years old, that represented differences in size of the crowns and thus, indirectly, differences in spacing, although the original spacings of those trees were not known.

Characteristics of Fibril Orientation

It is commonly accepted that cell walls of softwood fibers include single-layer primary walls and secondary walls with a thin outer layer, but, of great importance, an appreciably thicker central layer besides a thin inner layer.[3] In general, the consensus of numerous investigators is that the cell walls are made up of strands that include many cellulose molecules that originate from the contents of living cells as the fibers develop in the tree. Arrangement of these strands, or fibrils, in the central layer of the secondary wall are of primary importance in relations of structure of wood to its properties, because that layer is an appreciable proportion of the total thickness of the cell wall. The central layer of the secondary cell wall is made up of approximately parallel fibrils, but orientation of those fibrils to the length of the fibers is widely variable from small to large angles.

There are numerous indications that the fibril angles contribute importantly to properties of the wood as a whole. Previous research had indicated that nominal fibril angles of less than 10° in summerwood fibers were associated with small longitudinal shrinkage in wood of the southern yellow pines. Relatively large fibril angles in springwood, some forms of normal summerwood, and the abnormal compression wood of softwoods were found to be associated with much larger shrinkage along the grain than the typically small longitudinal shrinkage of 0.1 to 0.3 percent of the green length of test pieces.[4] Smaller values in certain strength properties of compression wood than of normal wood were associated with the intrinsically large fibril angles of compression wood.[5] Increase in size of

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[3]Bailey, I. W., and Vestal, Mary R. The Orientation of Cellulose in the Secondary Wall of Trachary Cells. Jour. Am. Arbor., Vol. 18, No. 3, 1937.

[4]Koehler, Arthur. Longitudinal Shrinkage of Wood. Forest Products Laboratory Report No. R1093. Revised September 1946.

[5]Pillow, M. Y., and Luxford, R. F. Structure, Occurrence, and Properties of Compression Wood. U. S. Dept. of Agriculture Tech. Bul. 546. January 1937.

fibril angles also was correlated with decrease in certain important strength properties of white ash essentially independent of specific gravity. Large fibril angles in both sulfite and sulfate pulp were associated with lesser tearing strength compared to small fibril angles in southern yellow pine.[6]

For the present work, fibril angles were determined only for normal summerwood. The fibril angles in summerwood always are smaller than in springwood of the same annual ring; and that relationship of size of fibril angles appears to be reasonably consistent, so that large angles in the summerwood reflect proportionately larger angles in the springwood of any annual ring. In addition, the proportion of the central layer in the secondary wall to the total cell wall of each kind of fiber is much greater in summerwood than in springwood. Those factors, together with greater accuracy in the determinations, led to selection of summerwood for determination of the sizes and patterns of fibril angles in the present work on loblolly pine.

Characteristics of Sample Trees

The sample trees for this work included two age classes, namely, 10 to 15 years and 30 to 35 years old. All trees were growing on sites of good quality, estimated at 90 feet high or more at 50 years, on the Crossett Experimental Forest and had originated from natural seeding. So far as information was available at that experiment station, no logging for commercial products had been done near the sample trees until shortly before they were selected and cut for this work in June 1951. Overtopping hardwoods, however, had been removed so that certain trees of the 10- to 15-year age class showed effects of that release for several years before selection of the sample trees.

Data on sizes of the sample trees are listed in table 1. The selection of samples was made to obtain approximately average trees of the 10- to 15-year-old stands, but trees that were representative of the range of the dominant and codominant trees in the 30- to 35-year-old stand.

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[6] Pillow, Maxon Y., Chidester, Gardner H., and Bray, Mark W. Effect of Wood Structure on Properties of Sulfate and Sulfite Pulps from Loblolly Pine. So. Pulp and Paper Journal, December 1941.

10- to 15-year Age Class

Thicket-grown. --Representative trees of a small, closely spaced stand were selected from a small area. The spacings of those trees varied from 2 feet to nearly 4 feet at an age of about 13 years. Originally the trees appeared to have been even more closely spaced because of some dead trees in the stand. The sample trees were 2 to 3 feet from their nearest neighbors, and had crowns as symmetrical as it was possible to select. The average length of crown of those trees was about 39 percent of the total heights of the trees.

An estimate of areas of crown surfaces was calculated for each sample tree on the basis of the surface of a cone equal to the average radius and length of the crowns. Those calculations were intended to give reasonable values of crown area for comparisons between sample trees as represented by the profile of a cone based on measurements of the crowns of the trees (table 1). The estimates undoubtedly were less than the total surface represented by somewhat curved edges in the profile of the crowns rather than straight edges of a cone. Underestimation of the total surface is a reasonable evaluation of crown area, however, since each crown contains some voids in its surface that are not occupied by secondary branches with needles.

Open-grown. --The samples of open-grown trees were in less competition with their neighboring trees for light and for soil moisture than the thicket-grown trees. The total heights of the open-grown trees were greater than those of the thicket-grown trees in the 10- to 15-year age. The length of crowns of the open-grown trees was an average of 64 percent of the total height of the trees. The greater lengths and also widths of the crowns of open-grown trees than those of thicket-grown trees resulted in much larger crown surfaces for the open-grown trees (table 1). Figure 1 shows graphically differences in height and crown size of typical thicket and open trees. Thus, extremes of growth conditions were represented by the differences in spacing of those two groups of trees.

Released. --A change in environment affecting individual trees was represented by trees, 10 to 15 years old, that had been released from overtopping hardwoods. The effect of release was apparent from the increased width of the last seven complete annual rings of the sample trees (fig. 2). Besides the change in environment due to release, the samples also represented difference in spacing that was reflected by their breast-height diameters, total heights, and comparative crown surfaces (table 1). That is, one released tree had general characteristics similar to the continuously open-grown trees, while the other tree was more like the thicket-grown ones.

30- to 35-year Age Class

The stand from which sample trees in the 30- to 35-year age were selected included a few large dominant trees and also smaller dominants, mostly of sawlog size, besides numerous codominants of pole sizes. The sample trees represented the small to large codominant trees and the larger dominants in an even-age stand. The range of total heights and sizes of the crowns of sample trees are shown graphically in figure 1 for typical trees, 30 to 35 years old, and their measurement data are given in table 1.

Specimens and Procedures for Determinations

The data on width of annual rings and size of fibril angles were determined along a selected radius in each cross-sectional disk from which specimens were taken for measurement of those features of the wood. The position of those disks above the ground always included approximate breast height and about the middle of the first interwhorl below and the second interwhorl above the base of the active crown of the saplings and the second-growth forest trees. Additional disks were taken at an intermediate height of about 12 feet for the trees 30 to 35 years old (table 2).

The sizes of fibril angles were determined in typical summerwood fibers for the succession of annual rings from the pith towards the bark. The typical summerwood of loblolly pine has thicker fiber walls and radially narrower cavities, as well as smaller bordered pits, than springwood. In the outer summerwood part of the first annual ring, however, typical summerwood fibers were absent, although the outer fibers were appreciably narrower than earlier fibers of that ring (fig. 3). Therefore, the determinations of fibril angles included only the succession of complete rings from the second ring from the pith towards the bark in order to restrict the data to typical summerwood.

The transition within an annual ring from springwood to summerwood was abrupt, mostly including a few fibers, so that typical summerwood was identified readily at the magnifications necessary for measurement of the fibril angles. Frequently, summerwood was present only in one zone in the outer part of the ring; however, in certain annual rings, there apparently were several alternate zones of springwood and summerwood. With such multiple zones of summerwood, only the outer zone of an annual ring showed a clearly defined boundary at the seasonal termination of the rings that was clearly visible even at small magnifications (fig. 3). Annual rings with more than one zone of summerwood were most common with the first several rings from the pith and appeared to be associated with periodic growth in height in 1 year, which has been observed commonly in the southern yellow pines.

The fibril structure of the central layer of secondary cell walls in normal fibers is not visible even at large magnifications with a light microscope. Nevertheless, the arrangement of fibrils in that layer can be determined by minute splits in the fiber wall that occurred where wood rays crossed the fibers[3] (fig. 4). Numerous observations have shown reasonable agreement between determinations of fibril angles made by means of those splits and by other methods including polarized light, X-rays, and the visible checks in the fiber walls of compression wood.

The fibril angles were determined by the angular deviation to the length of the fibers of the small splits in the central layer of the secondary cell wall. Radial microtome sections stained with safranin and permanently mounted were used for those measurements in summerwood fibers. Magnifications of about 400 times were used with a microscope equipped with a revolving stage and fixed occular cross hairs for determining differences between alinement of the splits and longitudinal axes of the fibers.

In some fibers, the minute splitting at ray crossings was either obscure or entirely absent, a condition that was found most commonly in summerwood of annual rings near the pith and having large fibril angles. That difficulty was overcome by treating radial sections with chloriodide of zinc,[7] a reagent that causes some swelling in excess of the nominal green or soaked conditions of the wood. The treatment consisted of two applications of that reagent, respectively, for 5 to 10 minutes each, and then washing in water until coloring caused by the reagent was practically all removed. The sections were dehydrated successively in 50, 70, and 95 percent ethyl alcohol and mounted directly in colorless diaphane[8] instead of in the natural or synthetic resins commonly used for permanently mounting of microtome sections.

Shrinkage of the central layer of the secondary cell wall after being excessively swollen by the chloriodide of zinc seemed to cause increased splitting at the ray crossings. Such splitting, however, tended to be obscured if the sections were mounted in natural or synthetic resins after being completely dehydrated by absolute alcohol and cleared in xylol and clove oil. The treatment with chloriodide of zinc was found to be reasonably simple and convenient to use as a histological technique for inducing or increasing minute splitting parallel to fibril arrangement in the central layers of the secondary cell walls.

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[7] Sass, John E. Elements of Botanical Microtechnique. 1940.
[8] Johansen, Donald Alexander. Plant Microtechnique. 1940.

The average fibril angles in degrees were based on 35 measurements that represented entire widths of the zones of typical summerwood in the respective annual rings. That number of measurements was calculated from the variability for certain annual rings with large or small fibril angles in order to obtain estimates of the average within plus or minus 10 percent for a probability level of 95 percent.

Variability in Fibril Angles

The average fibril angles in normal summerwood fibers of the sample trees showed a large range of variation from 2° to 51°, but the variability in the size of fibril angles followed certain general trends or patterns. The fibril angles tended to decrease in successive annual rings from the second ring towards the bark, and wide annual rings tended to have larger average angles than narrow rings.

10- to 15-year Age

The open-grown and thicket-grown trees that represented extremes of wide and close spacings, respectively, had been selected in order to compare the environmental effects of competition between trees on sizes of fibril angles in consecutive annual rings and also in relation to width of the annual rings. The trees released from overtopping hardwoods represented a change in spacing that affected individual trees; thereby, possible effects of genetical factors were excluded from the effects of spacings before and after release.

Average fibril angles at breast height in the succession of annual rings of open-grown trees were much larger than those of thicket-grown trees 10 to 15 years old. The differences in fibril angles between those spacings, however, were relatively smaller at the heights just below and above the base of the active crown. The annual rings in open-grown trees were consistently wider than in the thicket-grown at all heights. Figures 5, 6, and 7 show the comparisons of the fibril angles and of width of annual rings in succession from the pith towards the bark for the open-grown and thicket-grown trees, respectively, at breast height and at first interwhorl below and second interwhorl above the base of the active crown. The extremes of fibril angles are shown in figure 8; that is, the large angles in the inner annual rings of the open-grown trees compared to small angles in outer rings of thicket-grown trees.

The fibril angles in the released trees, which had started as seedlings under hardwoods, tended to decrease in size in the early annual rings similarly to the decrease in the thicket-grown trees. After release from the hardwoods, however, the angles increased abruptly in association with increases in width of the annual rings. The released tree with a large crown had greater fibril angles and also wider rings than the one with a relatively small crown (fig. 9). Thus, vigor of growth of the trees, as reflected by sizes of the crowns in the open-grown and thicket-grown trees and in released trees (table 1), appeared to contribute to a general relation of fibril angles to width of annual rings.

Determinations were made of the relation of the fibril angles to width of the annual rings in the open-grown, thicket-grown, and released trees. Relatively larger differences in size of the angles were found between open-grown and thicket-grown trees at breast height as compared with the differences at the heights either above or below the base of the active crown. Therefore, it appeared reasonable to determine that relation separately for breast height and for the combination of the two levels below and above the base of the crowns in the trees 10 to 15 years old.

Trends of mutual relations between the fibril angles and the width of annual rings were shown by highly significant correlation coefficients, respectively, for the data both at breast height and close to the base of the crown. Plotting of the data indicated approximately linear increases in fibril angles for increases in width of the rings that were expressed by the regression:

$$Y = a + b\,(X)$$

where

Y = fibril angle in degrees
X = width of rings in inches, and
a and b = constants.

The thicket-grown trees represented one extreme of relatively small fibril angles and narrow rings as compared to the open-grown trees having larger angles and wider rings. Those features of the wood in released trees were intermediate between the extremes of spacing for the thicket-grown and open-grown trees. The relations of fibril angles to width of the rings were reasonably similar for the heights below and above the base of the active crown. That relation at breast height, however, was appreciably different than at the combined crown height; that is, the slope of the regression line was steepest at the breast height (fig. 10).

The data on fibril angles in normal summerwood of sapling trees showed certain independent trends of variability; namely, (1) decrease in the angles in successive annual rings from the pith toward the bark, (2) increase in the angles with increase in width of the rings, and (3) larger angles at breast height than at crown heights, particularly for relatively wide annual rings.

30- to 35-year Age Class

Variability in the average fibril angles in normal summerwood of the trees 30 to 35 years old showed trends of decreasing fibril angles in successive annual rings from the pith that were similar to the trends observed for the trees 10 to 15 years old. There was a general tendency for the fibril angles to decrease more gradually at breast height, particularly in the trees with intermediate and large sizes of crowns, than at the intermediate height between stump and the base of the active crown (fig. 11). The fibril angles below and above the crowns had similar patterns to those at the intermediate height. The patterns of the angles in the forest-grown trees, 30 to 35 years old, resembled more closely those of open-grown trees than those of the thicket-grown at the younger age.

In general, the estimated surfaces of crowns in the 30- to 35-year-old trees were related to differences in natural spacings from relatively close for the trees with small and intermediate crowns to open for the tree with a large crown surface (table 1). The fibril angles also varied in relation to the distance from the pith, which, in turn, reflected narrower annual rings in the trees with small and intermediate crowns than the rings in the tree with a large crown (fig. 12). A highly significant correlation coefficient showed a mutual relation of increased fibril angles with increase in width of the annual rings at breast height in the trees 30 to 35 years old. Although the separate correlation coefficients for that relation were not significant at the intermediate or crown heights, there was a similar trend of increased fibril angles with the width of the annual rings (fig. 13).

Thus, analysis of the data for trees 30 to 35 years old indicated that factors of (1) successive annual-ring number from the pith and (2) width of the ring contributed jointly to the variability in the fibril angles of normal summerwood. The patterns of variability in those angles for successive ring numbers at breast height also differed from patterns at intermediate or crown heights. Therefore, the relations of fibril angles jointly with successive ring numbers and widths of rings were determined separately for breast height and for the combination of intermediate and crown heights in the sample trees.

Trends of joint relations of one dependent variable feature of wood, such as fibril angles, with two other variable factors can be determined readily from alternate approximations with the latter variables. The functions of such joint relations when arranged in a three-dimensional graph show how one variable changes within successive classifications of two other variables. Thus, estimates of fibril angles in relative positions in successive annual rings from the pith and width of the rings are expressed by the shape of a continuous surface that is free to change with the effects of each of the latter variables even when they operate in opposite directions.[9]

For this work, convenient classifications were made for successive annual-ring numbers and for width of the rings. Since the relation of fibril angle to the width of annual rings tended to be linear (figs 10 and 13), the first approximations of fibril angles were made directly from the data that were calculated as regressions for each classification of successive ring number from the pith. Those regressions, in turn, supplied estimates of fibril angles for the classifications of width of rings that were plotted for the second approximation to estimate fibril angles in relation to successive ring numbers. Subsequent approximations were made alternately until the estimated values for fibril angles closely fitted the approximation lines.

The fibril angles, estimated from the final approximations, decreased with the successive ring numbers from the pith in curved relationships for each classification of width of rings at both breast height and the combination of intermediate and crown heights of the forest trees. On the other hand, the fibril angles increased with width of rings in linear relationships. Figures 14 and 15 show graphically changes in fibril angles as joint functions of successive ring numbers from the pith and width of the rings, and tables 3 and 4 list the estimated fibril angles in comparison with measurement data in the different classifications, respectively, at breast height and combined intermediate and crown heights.

Those determinations showed that fibril angles were generally larger at breast height than at the combined intermediate and crown heights. Nominal fibril angles of less than 10° have been found to be associated with average, or greater, strength properties and with longitudinal shrinkage of 0.1 to 0.3 percent for southern yellow pine wood. Such nominal fibril angles first occurred in the sixth to tenth successive rings from the pith and outward at the intermediate and crown heights, more or less, irrespective of width of the annual rings (table 4). At breast height, however, such small angles occurred only at greater successive ring numbers from the pith (table 3).

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[9] Ezekiel, Mordecai. Methods of Correlation Analysis. 2nd Ed. John Wiley and Sons, New York. December 1947.

Conclusions

Within the limitations of the present study, certain conclusions on variability in sizes of fibril angles in normal summerwood are considered reasonable for second-growth loblolly pines having different spacings of naturally seeded trees, both at ages of 10 to 15 years and of 30 to 35 years.

1. The trends of decreases in fibril angles for successive rings from the pith occur in both sapling sizes and pole sizes of trees.
2. The environmental factors of spacings of the trees affect fibril angles so that closely spaced trees tend to have smaller angles than widely spaced trees of sapling size in the respective successions of annual rings from the pith.
3. The relation of fibril angles to the successive ring number is curved; however, the shapes of the curves are affected to some extent by widths of the annual rings. For closely spaced trees with small crowns, the decrease in fibril angles tends to be steeper in the succession of rings than for widely spaced trees with relatively larger crowns.
4. The effects of increased spacing for individual pines that had been released from overtopping hardwoods are reflected in increased fibril angles after such release.
5. The correlations between fibril angles and width of annual rings are essentially linear.
6. The relations of fibril angles jointly to successive annual ring number from the pith and width of the rings can be represented by three-dimensional graphs that show general patterns of variations in fibril angles that are somewhat different at breast height than at combined intermediate and crown heights.
7. The present study confirms the hypothesis that the combination of factors (a) of position from the pith of successive annual rings and (b) of environmental conditions that affect vigor of growth contribute importantly to variations in fibril angles.
8. The results of the study provide a basis for development of methods for future evaluation of sizes of fibril angles in standing trees from small blocks that can be chipped from outer annual rings when successive ring numbers and widths of rings are known from increment cores. Although there is no direct information at present that the sizes of the fibril angles are affected by genetical factors, as well as by environmental conditions, such information is highly desirable in selection and breeding of improved forest trees.

Table 1. --Ages and sizes of sample loblolly pine trees

Tree	Age at stump	Diameter (b. h.)	Total height	Crown size: Length	Crown size: Average maximum width	Crown size: Estimated surface area	Kind of stand
Number	Years	Inches	Feet	Feet	Feet	Square feet	
1	13	3.2	31.6	12.7	6.0	123	Thicket-grown saplings
2	13	3.4	31.6	12.1	7.0	139	Do.
6	11	7.8	39.5	23.6	12.0	458	Open-grown saplings
7	12	8.7	40.0	27.0	15.0	660	Do.
10	15	6.3	39.5	24.3	13.6	539	Released saplings
11	15	3.5	29.5	16.1	5.6	144	Do.
21	31	11.2	62.0	28.5	19.6	928	Pole or sawlog trees
24	32	9.9	71.0	26.8	11.2	485	Do.
25	33	22.8	80.0	47.7	34.0	2705	Do.

Table 2.--Height at base of active crown and of sample cross sections and their number of annual rings in second-growth loblolly pine trees

Kind of stand	Tree	Base of active crown	Height of section	Annual rings in section
	Number	Feet	Feet	Number
Thicket-grown, 10-15 years	1	....	4-5	12
Do.	1	....	17-18	8
Do.	1	18.9	....	....
Do.	1	....	22-23	6
Do.	2	....	4-5	12
Do.	2	....	17-18	7
Do.	2	19.5	....	....
Do.	2	....	23-24	5
Open-grown, 10-15 years	6	....	4-5	10
Do.	6	....	14-15	7
Do.	6	15.9	....	....
Do.	6	....	19-20	6
Do.	7	....	4-5	11
Do.	7	....	11-12	8
Do.	7	13.0	....	....
Do.	7	....	18-19	6
Released, 10-15 years	10	....	4-5	13
Do.	10	....	13-14	7
Do.	10	15.2	....	....
Do.	10	....	20-21	5
Do.	10	....	4-5	13
Do.	10	....	12-13	6
Do.	10	13.4	....	....
Do.	10	....	16-17	4
Poles or sawlogs, 30-35 years	21	....	4-5	30
Do.	21	....	12-13	25
Do.	21	....	31-32	16
Do.	21	33.5	....	....
Do.	21	....	38-39	13

(Sheet 1 of 2)

Table 2. --Height at base of active crown and of sample cross sections and their number of annual rings in second-growth loblolly pine trees (continued)

Kind of stand	Tree	Base of active crown	Height of section	Annual rings in section
	Number	Feet	Feet	Number
Poles or sawlogs, 30-35 years (continued)	24	....	4-5	31
Do.	24	....	12-13	28
Do.	24	....	42-43	16
Do.	24	44.2	....	....
Do.	24	....	48-49	15
Do.	25	....	4-5	32
Do.	25	....	12-13	30
Do.	25	....	29-30	25
Do.	25	32.3	....	....
Do.	25	....	37-38	22

(Sheet 2 of 2)

Table 3. --Estimated fibril angles at breast height in normal summerwood from approximations by two-way classifications of successive annual-ring number and width of rings in comparison with test data (in parentheses) for second-growth forest trees about 30 years old

Classes of rings from pith	Classes of width of rings (inch) --				
	0.0 - 0.09	0.10 - 0.19	0.20 - 0.29	0.30 - 0.39	0.40 +
Number	Degrees	Degrees	Degrees	Degrees	Degrees
2 - 5	27.0 (27.8)	28.0 [1](28.2)	29.5 (34.9)	31.0 (34.0)	32.8 ([2])
6 - 11	19.8 ([2])	21.5 [1](22.6)	23.0 [1](19.3)	24.5 (30.3)	26.0 [1](28.2)
12 - 17	14.0 (11.8)	16.0 [1](15.8)	17.5 ([2])	19.0 (22.4)	21.0 (18.4)
18 - 23	10.5 ([2])	12.0 [1](13.2)	13.5 [1](16.9)	15.0 [1](14.4)	17.2 ([2])
24 - 29	7.2 [1](9.0)	8.5 [1](9.3)	10.0 (11.8)	11.5 ([2])	12.8 ([2])
30 +	4.0 (6.5)	5.0 [1](4.4)	6.5 ([2])	7.5 ([2])	8.0 ([2])

[1] Average of two to seven specimens within the classification.

[2] Indicates no test data.

Table 4.--Estimated fibril angles at combined intermediate and crown heights in normal summerwood from approximations by two-way classifications of successive annual-ring number and width of ring in comparison with actual data for second-growth forest trees about 30 years old

Classes of rings from pith	Classes of width of rings (inch) --				
	0.0 - 0.09	0.10 - 0.19	0.20 - 0.29	0.30 - 0.39	0.40 +
Number	Degrees	Degrees	Degrees	Degrees	Degrees
2 - 5	15.9 (1)	16.0 [2](17.4)	16.1 [2](17.3)	16.3 [2](16.9)	16.4 (1)
6 - 10	8.6 (1)	8.8 [2](9.5)	9.0 [2](8.2)	9.2 [2](9.9)	9.4 [2](9.5)
11 - 15	5.6 (4.1)	5.8 [2](5.8)	6.0 [2](5.2)	6.2 (7.0)	6.4 (9.1)
16 - 20	4.2 (6.4)	4.4 [2](4.1)	4.6 [2](4.3)	4.8 (1)	5.0 (1)
21 +	3.4 (1)	3.6 [2](3.5)	3.7 (3.9)	3.9 (1)	4.0 (1)

[1]Indicates no test data.

[2]Average of two to nine specimens within the classification.

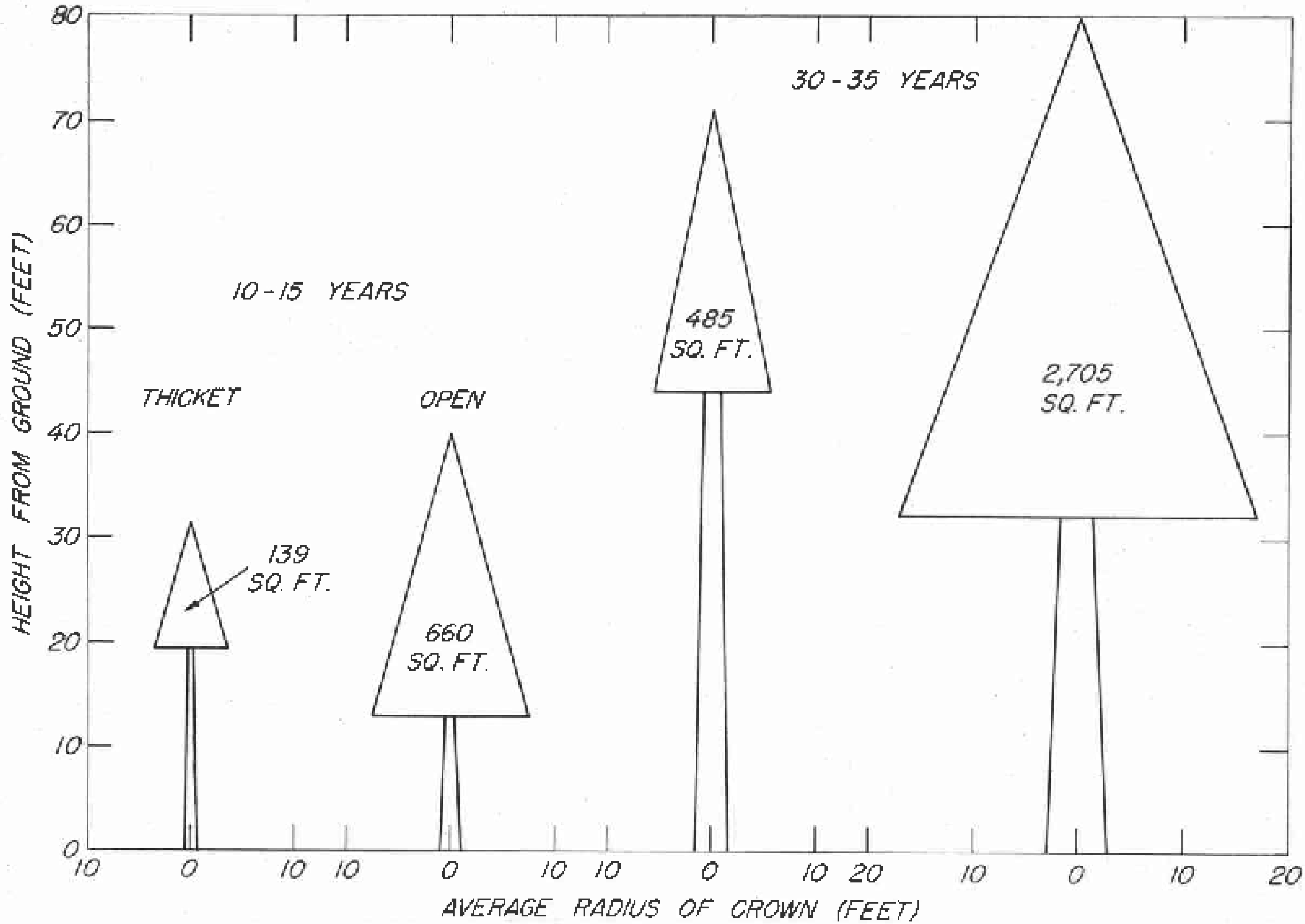

Figure 1. --Comparison of total heights and crown sizes of typical trees. Left, thicket-grown and open-grown, 10 to 15 years old; and, right, with small and large crowns, 30 to 35 years old. (Estimated crown surface in square feet.)

Z M 92299 F

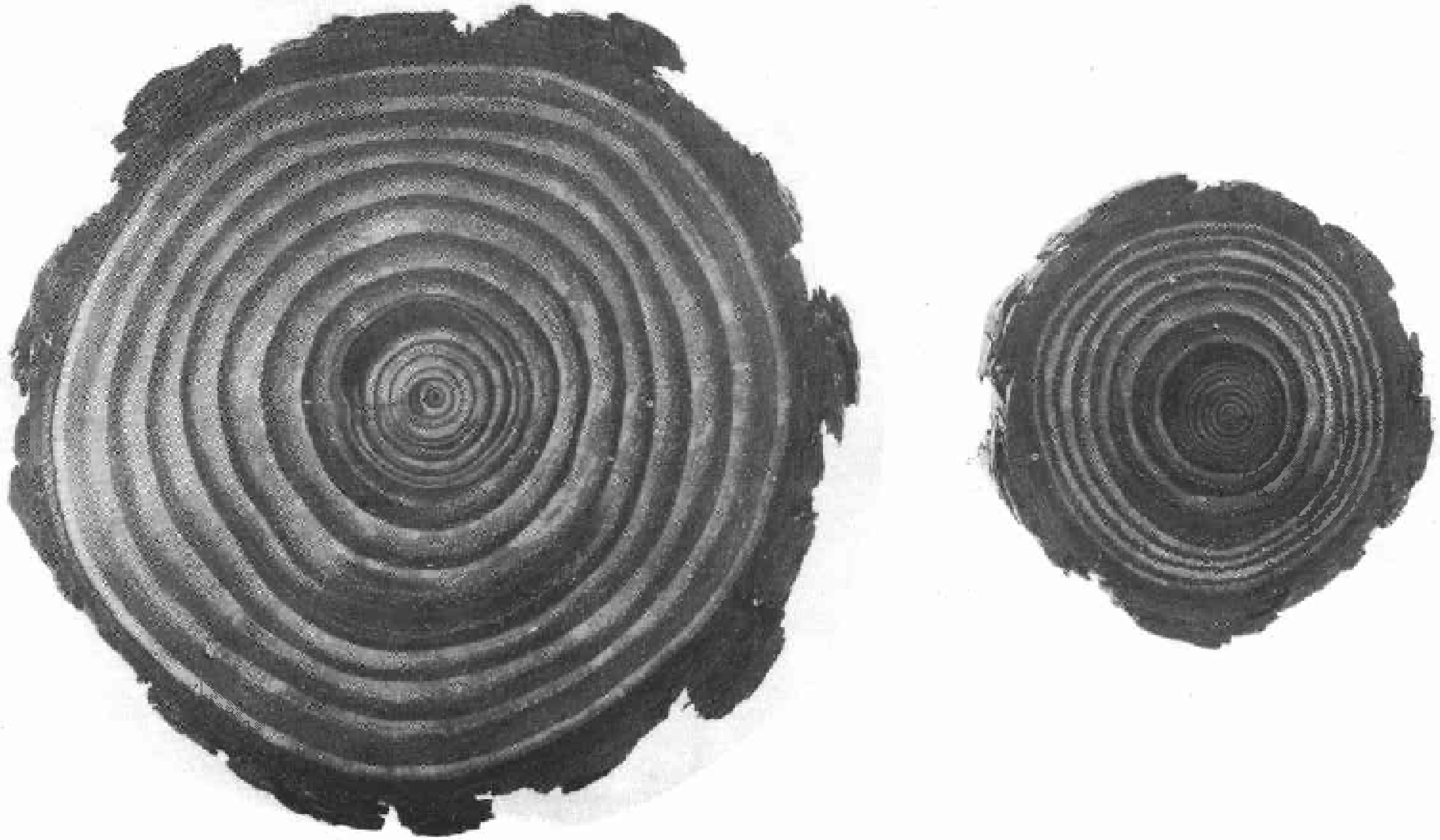

Figure 2. --Cross sections near stump of loblolly pine saplings released by removal of overtopping hardwoods. Left, large crown; right, small crown.

ZM 91348 F

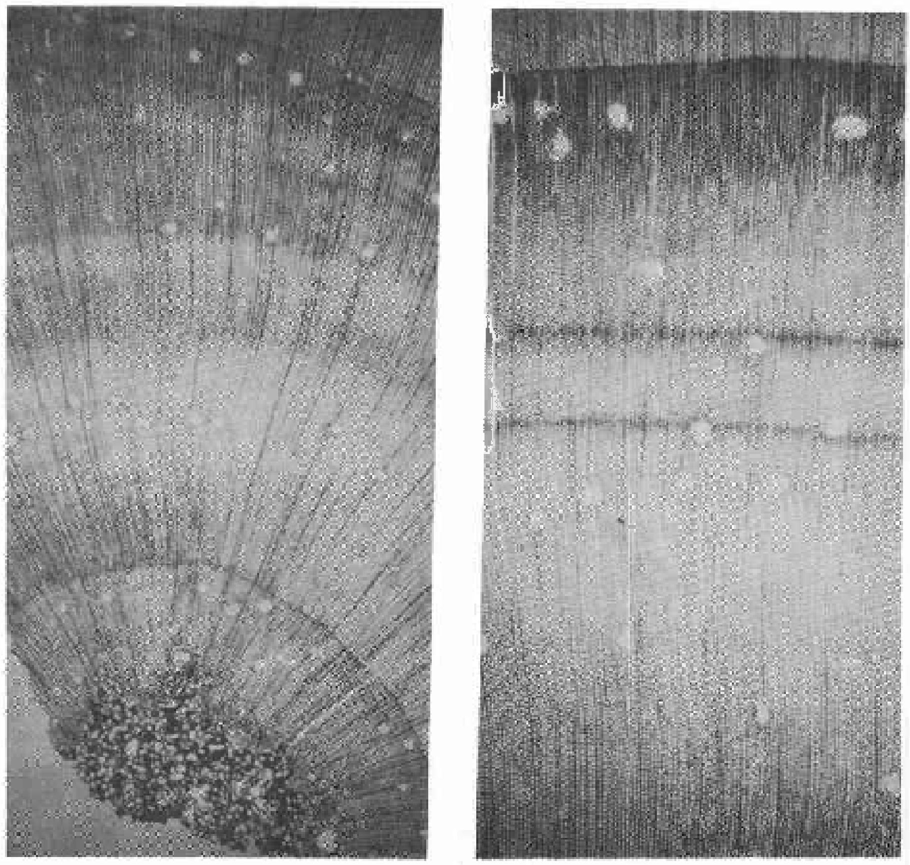

Figure 3. --Cross sections showing annual rings in second-growth loblolly pine. Left, the first annual ring and pith at the bottom and the second ring that includes zones of summerwood interspersed by springwood; and, right, part of one ring with two narrow zones of summerwood and the typical zone of summerwood that forms the outer boundary of the annual rings. X 20.

ZM 89418 F

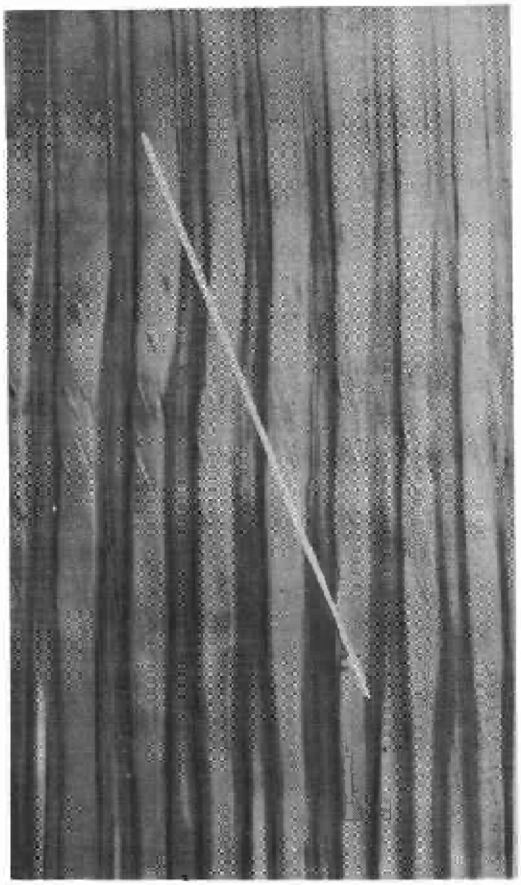

Figure 4. --Radial section showing splits in the central layer of the secondary cell wall that are parallel to its fibril arrangement in normal summerwood. X 500.

ZM 91350 F

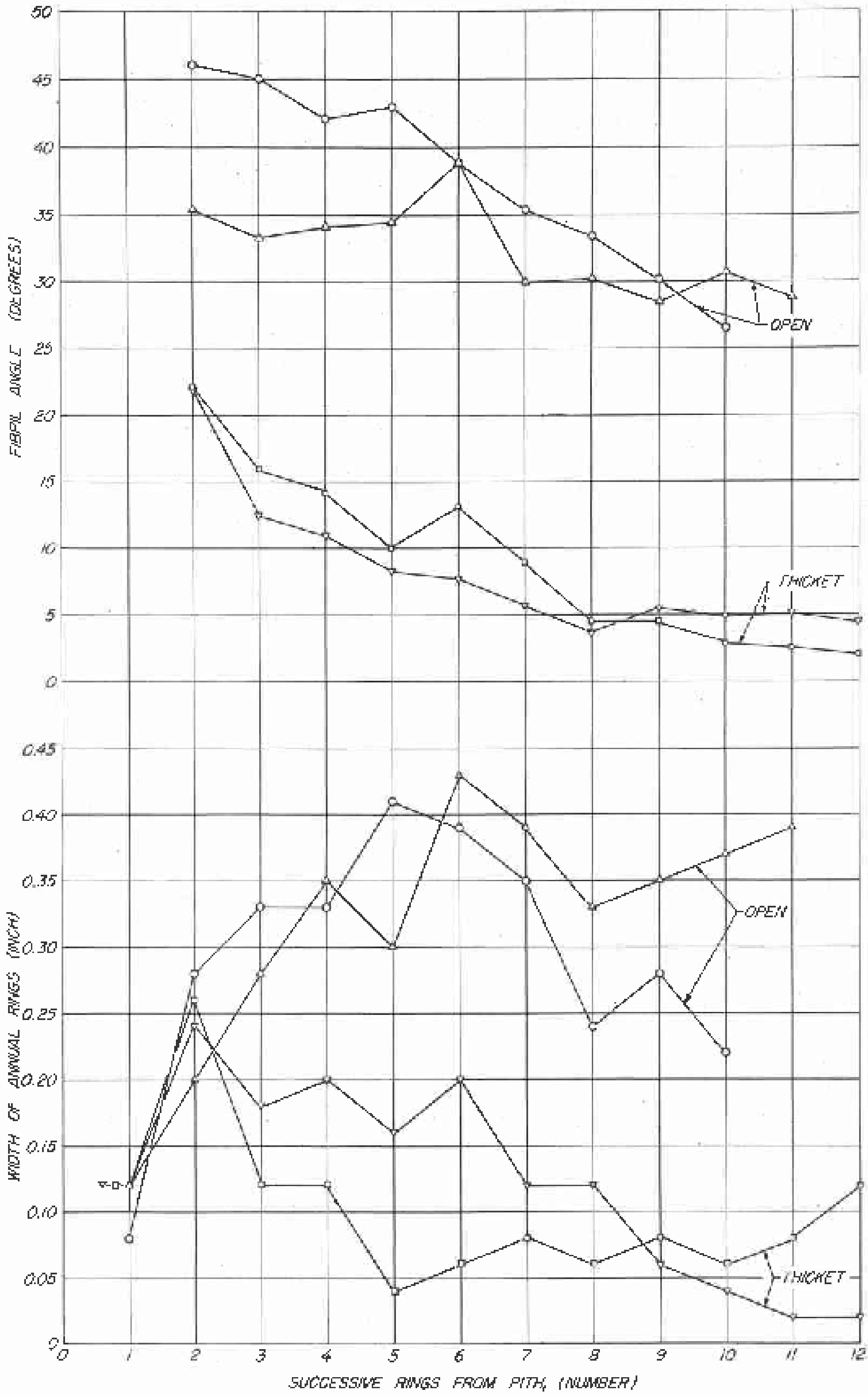

Figure 5. --Comparisons of average fibril angles at breast height in normal summerwood and width of annual rings for the successive rings from the pith in open-grown and thicket-grown trees 10 to 15 years old.

Z M 92300 F

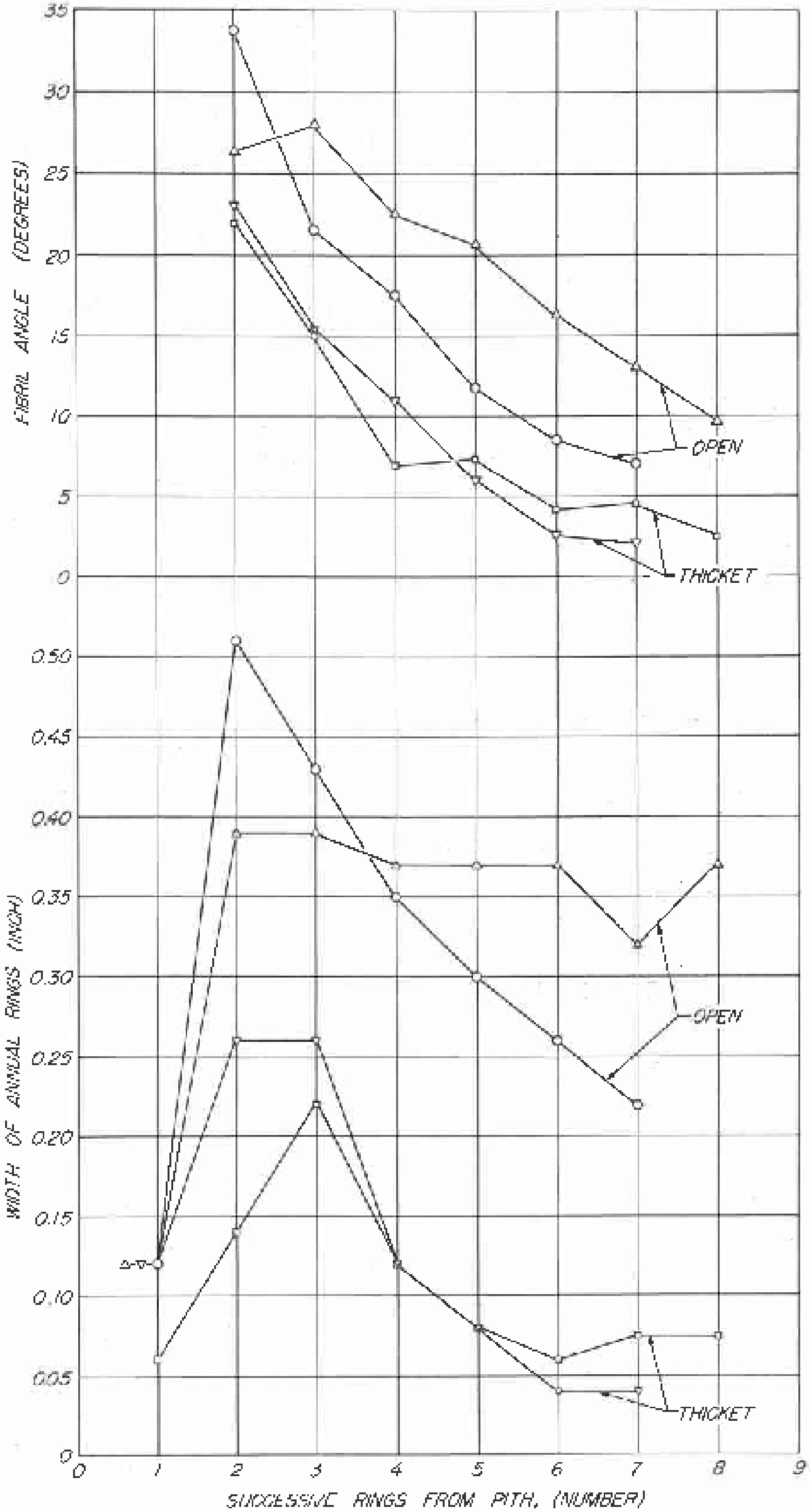

Figure 6. --Comparison of average fibril angles below the base of active crown in normal summerwood and width of annual rings for the successive rings from the pith in open-grown and thicket-grown trees 10 to 15 years old.

Z M 92301 F

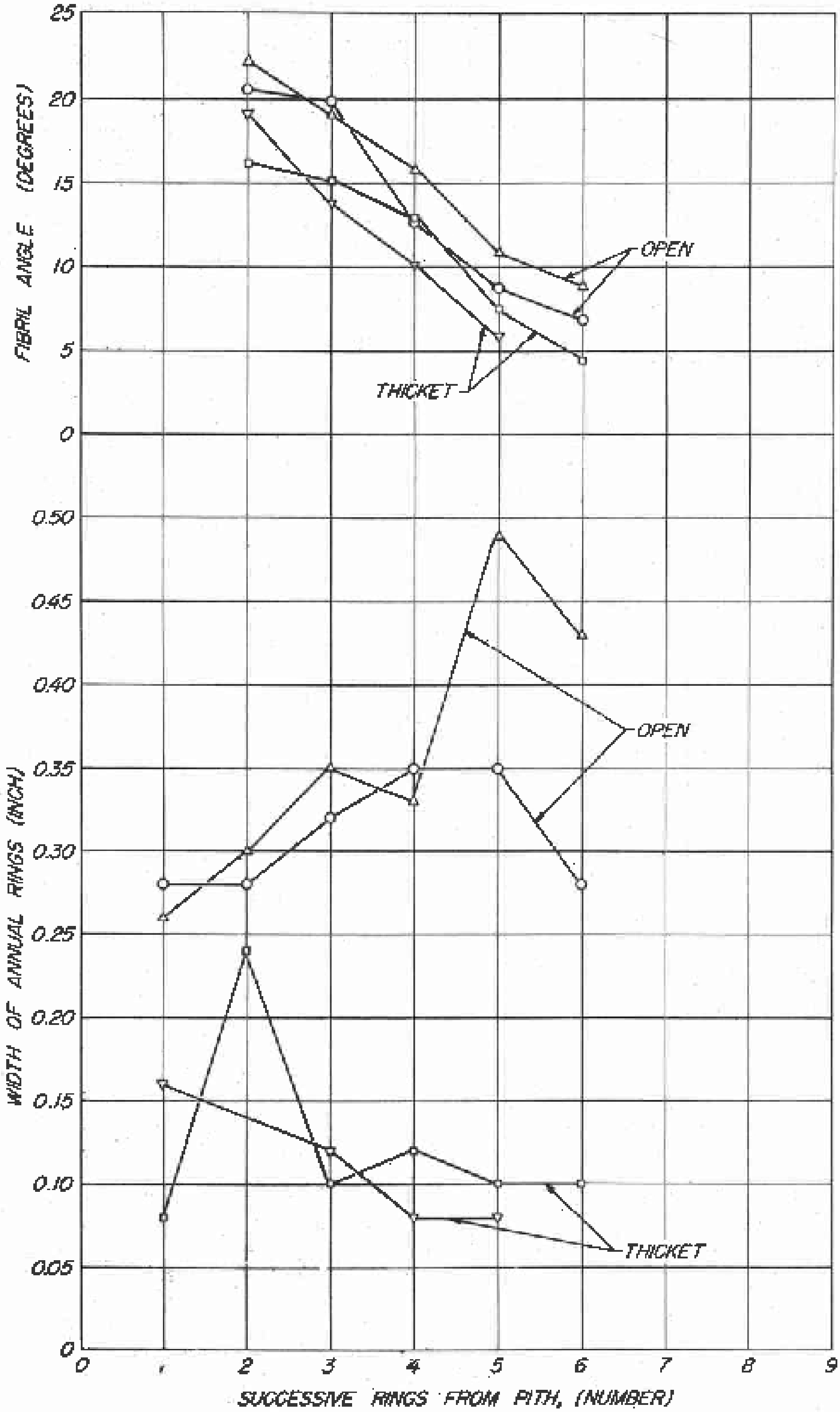

Figure 7. --Comparison of average fibril angles above the base of active crown in normal summerwood and width of annual rings for the successive rings from pith in open-grown and thicket-grown trees 10 to 15 years old.

Z M 92302 F

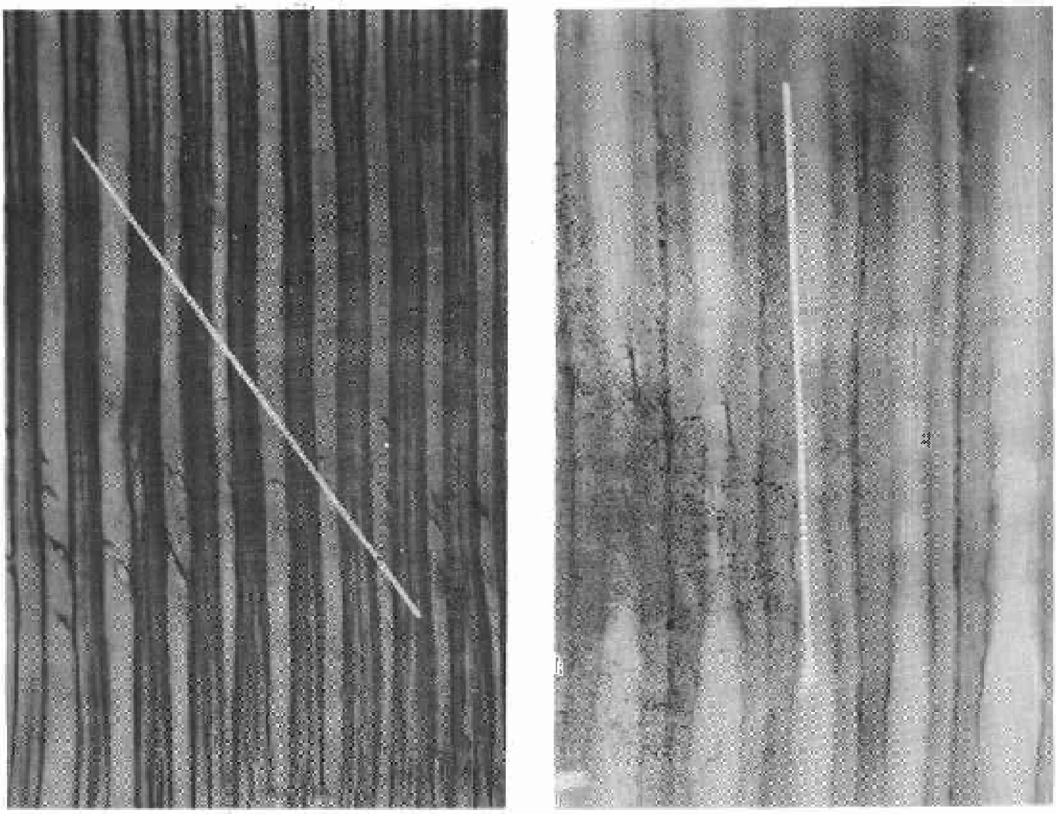

Figure 8. --Radial sections showing extremes of fibril arrangement. Left, large fibril angles; and right, small fibril angles in normal summerwood of loblolly pine.

ZM 91351 F

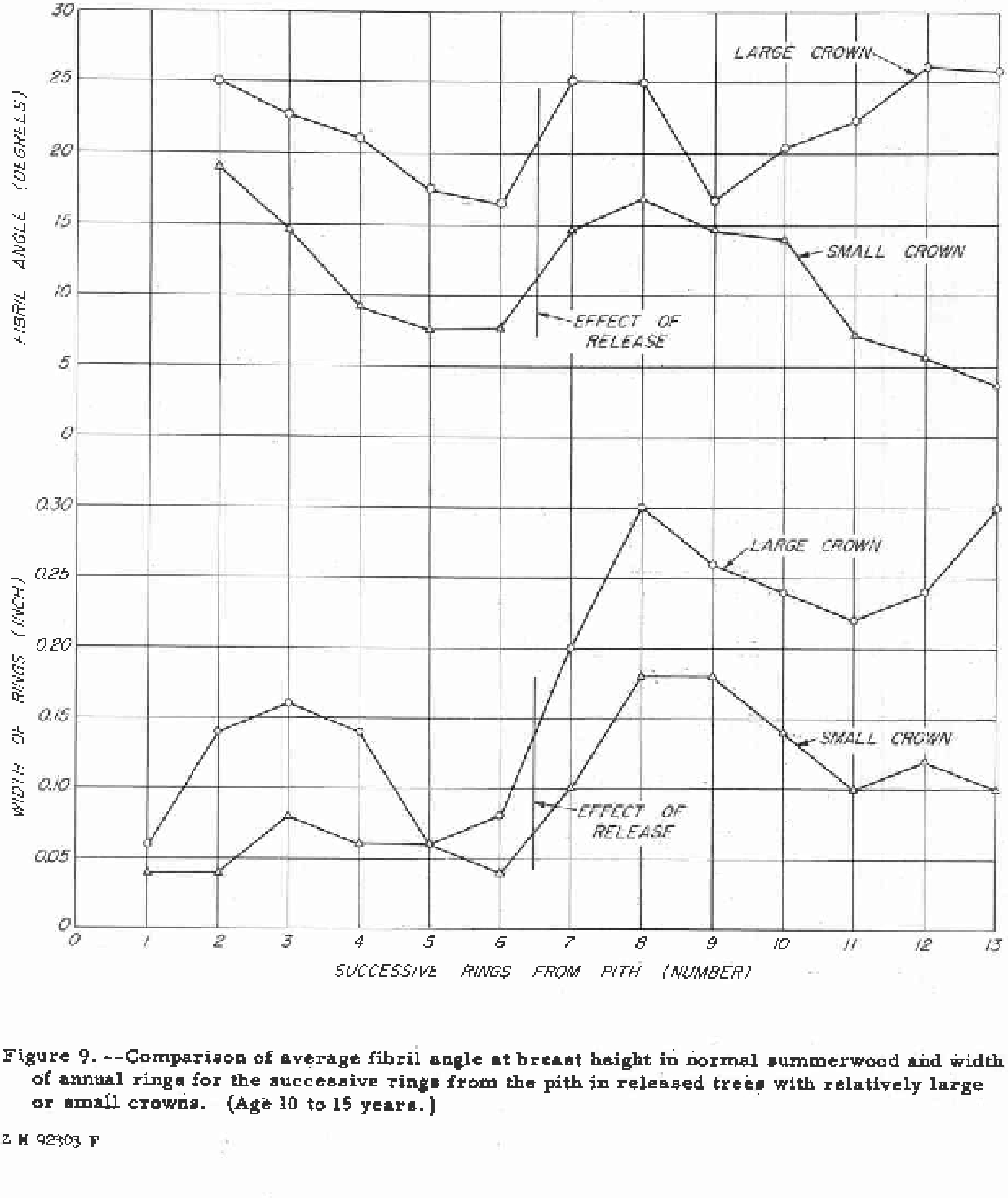

Figure 9. --Comparison of average fibril angle at breast height in normal summerwood and width of annual rings for the successive rings from the pith in released trees with relatively large or small crowns. (Age 10 to 15 years.)

Z M 92303 F

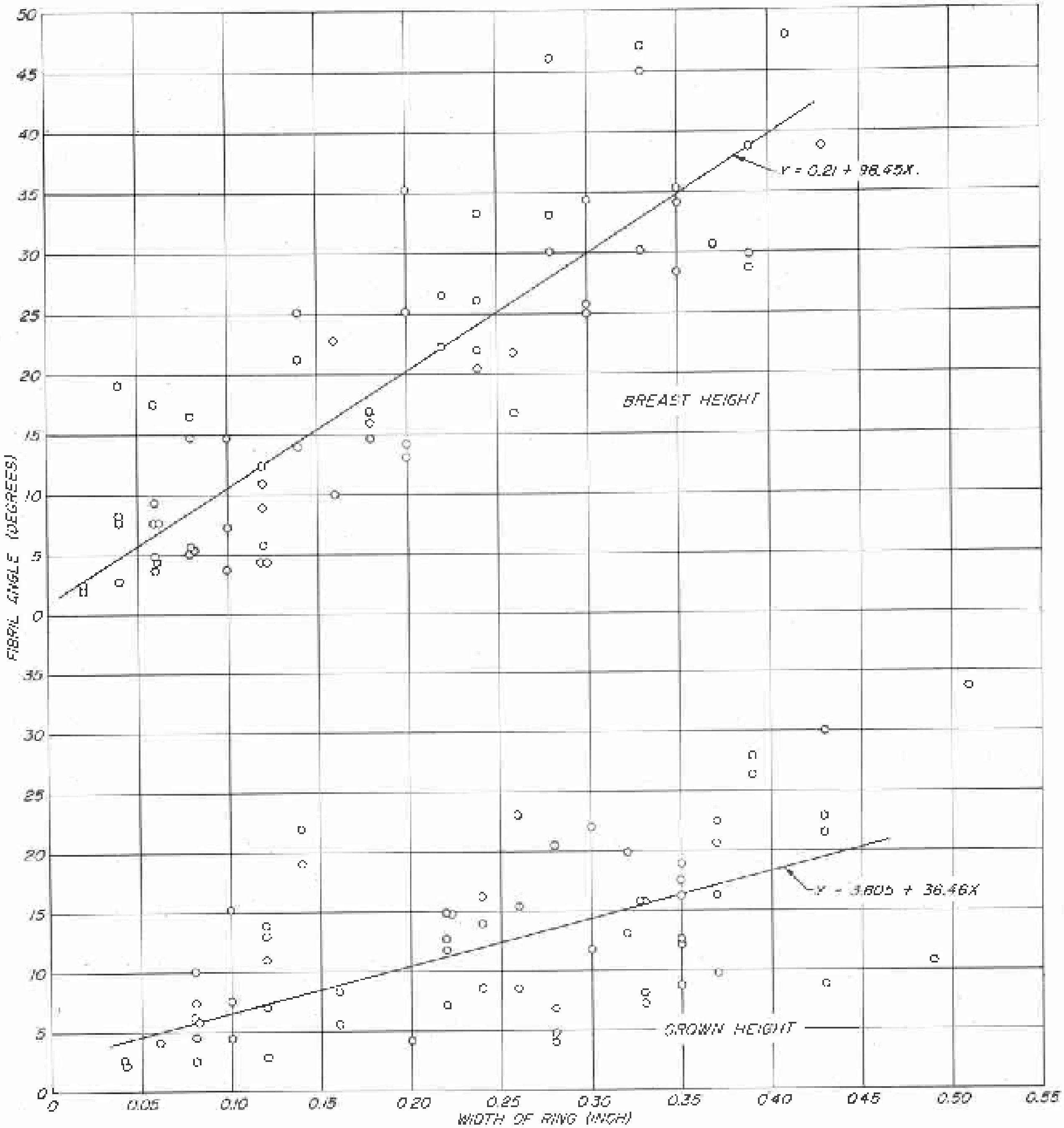

Figure 10. --Relations of average fibril angles in normal summerwood to width of the annual rings in thicket-grown, open-grown, and released trees, respectively, at breast height and close to the base of active crown. (Age 10 to 15 years.)

Z M 92304 F

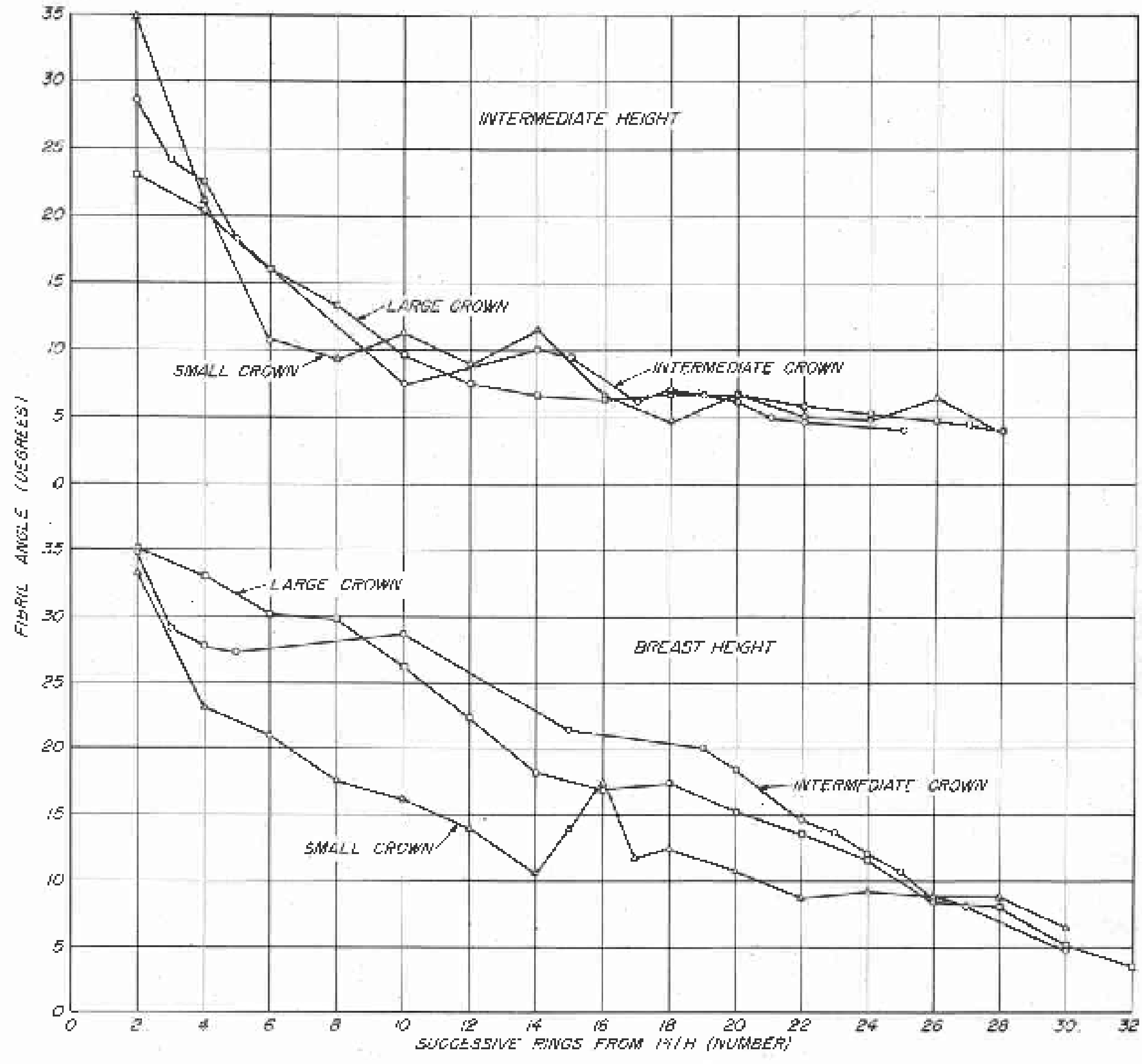

Figure 11. --Comparisons of average fibril angles in normal summerwood in the succession of annual rings from the pith towards the bark of forest trees at the breast and intermediate heights to below the base of the active crown in trees 30 to 35 years old.

Z M 92305 F

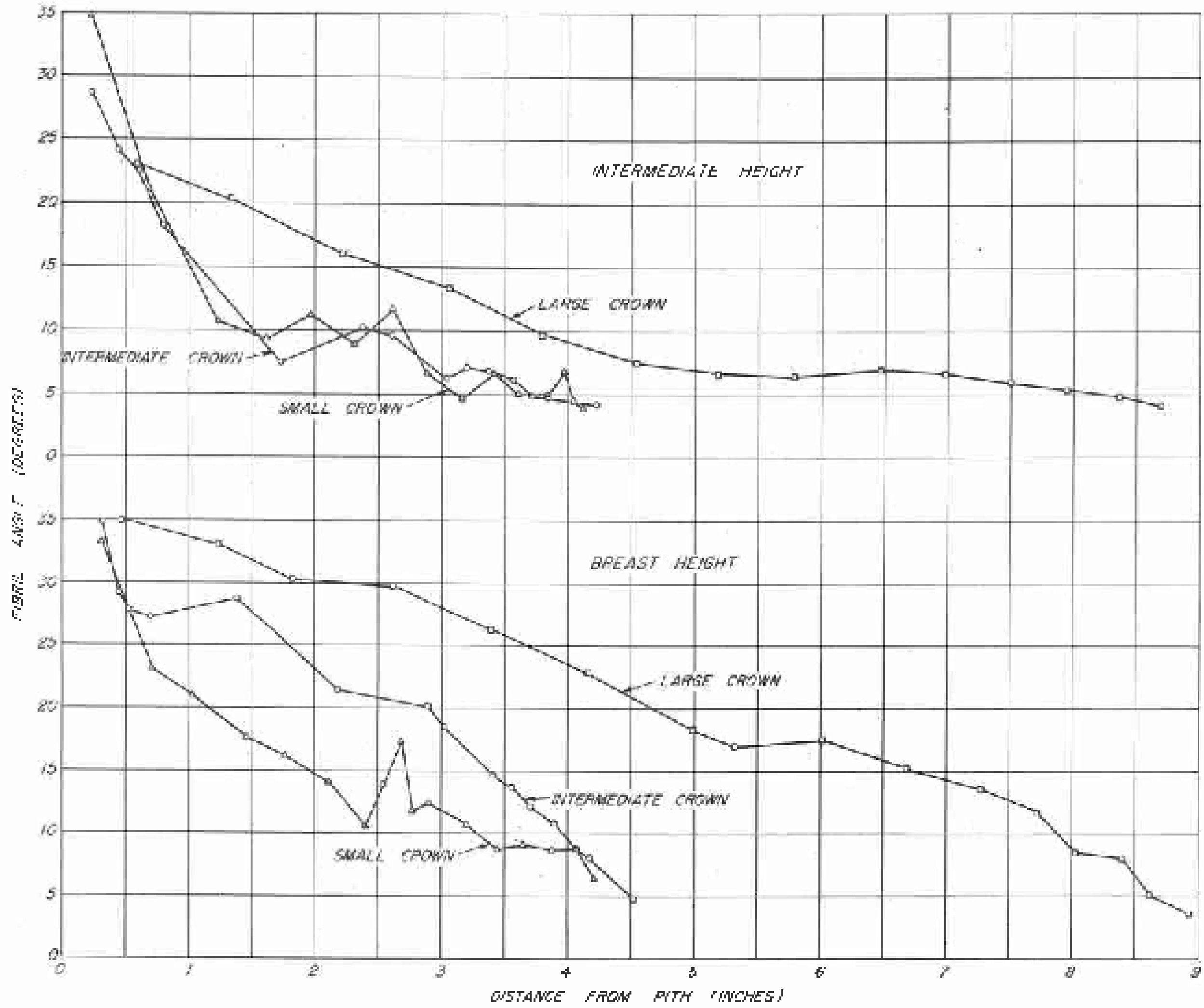

Figure 12. --Comparisons of average fibril angles in normal summerwood in relation to distance from the pith at heights with respect to the base of the active crown in trees 30 to 35 years old.

Z M 92306 F

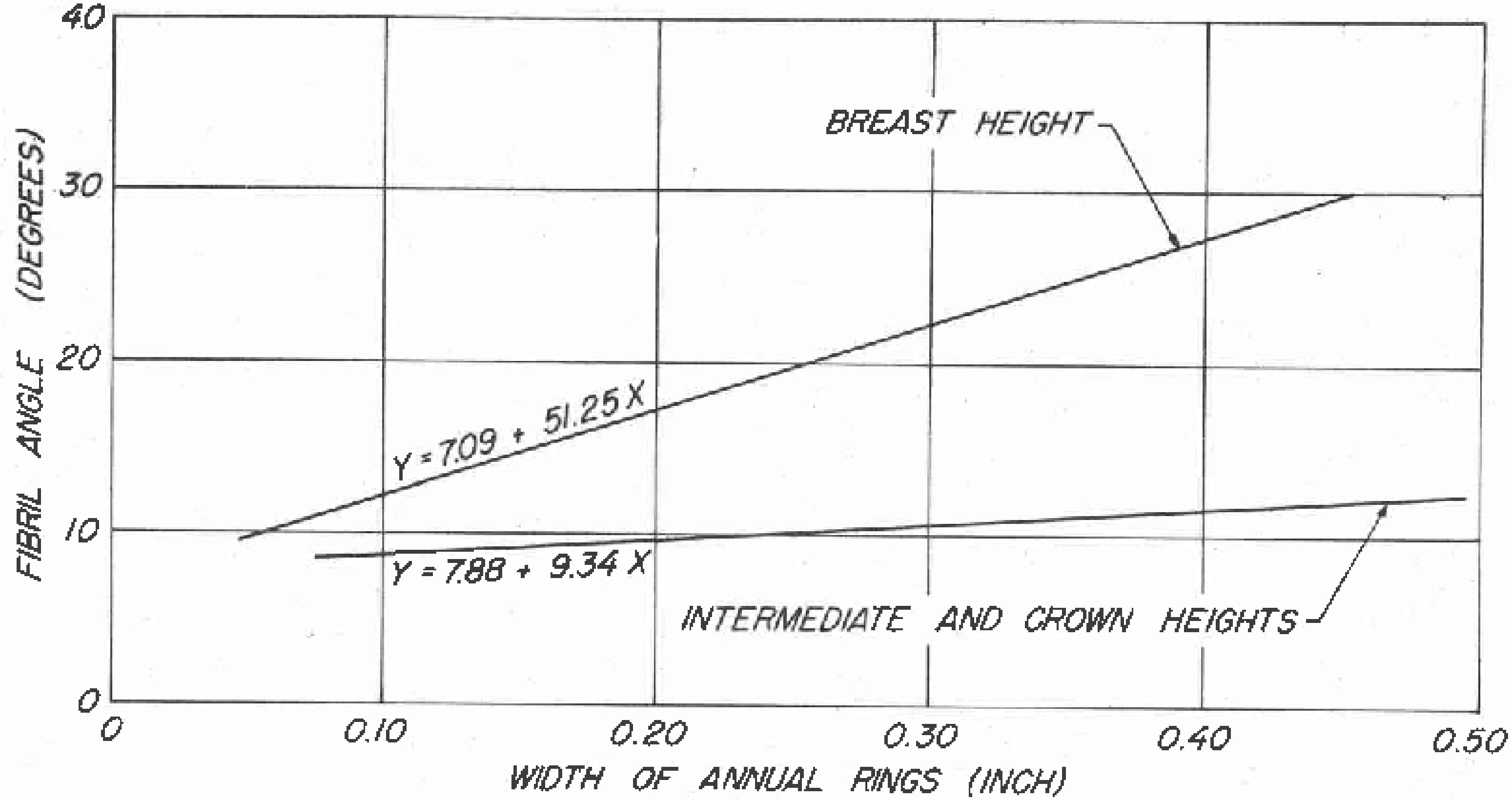

Figure 13. --Relations of average fibril angle in normal summerwood to width of annual rings at breast height and at the combination of intermediate and crown heights in trees 30 to 35 years old.

Z M 92307 F

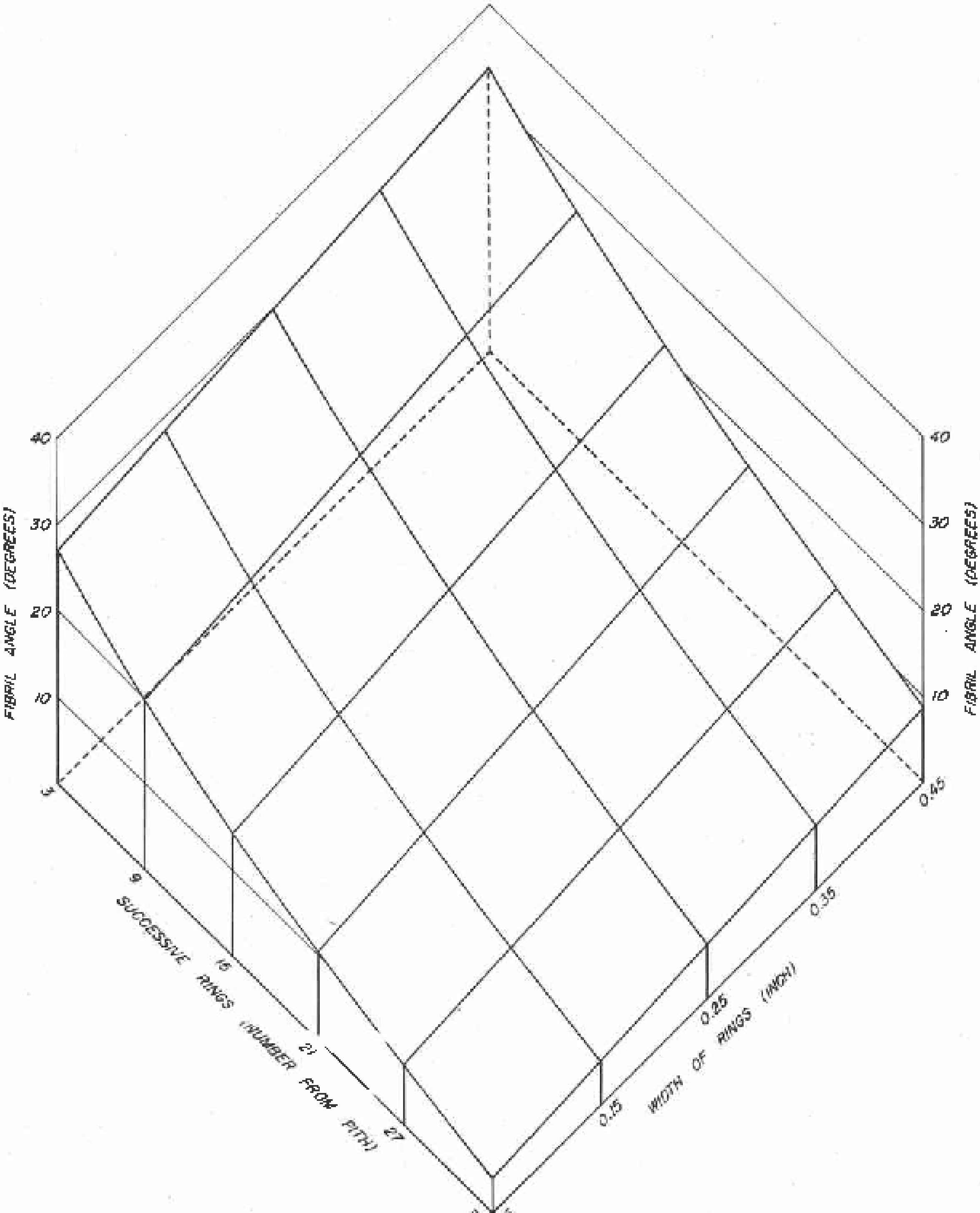

Figure 14. --Joint relations of fibril angles to the successive annual ring number from the pith and the width of rings at breast height of loblolly pine, 30 to 35 years old.

2 M 92308 F

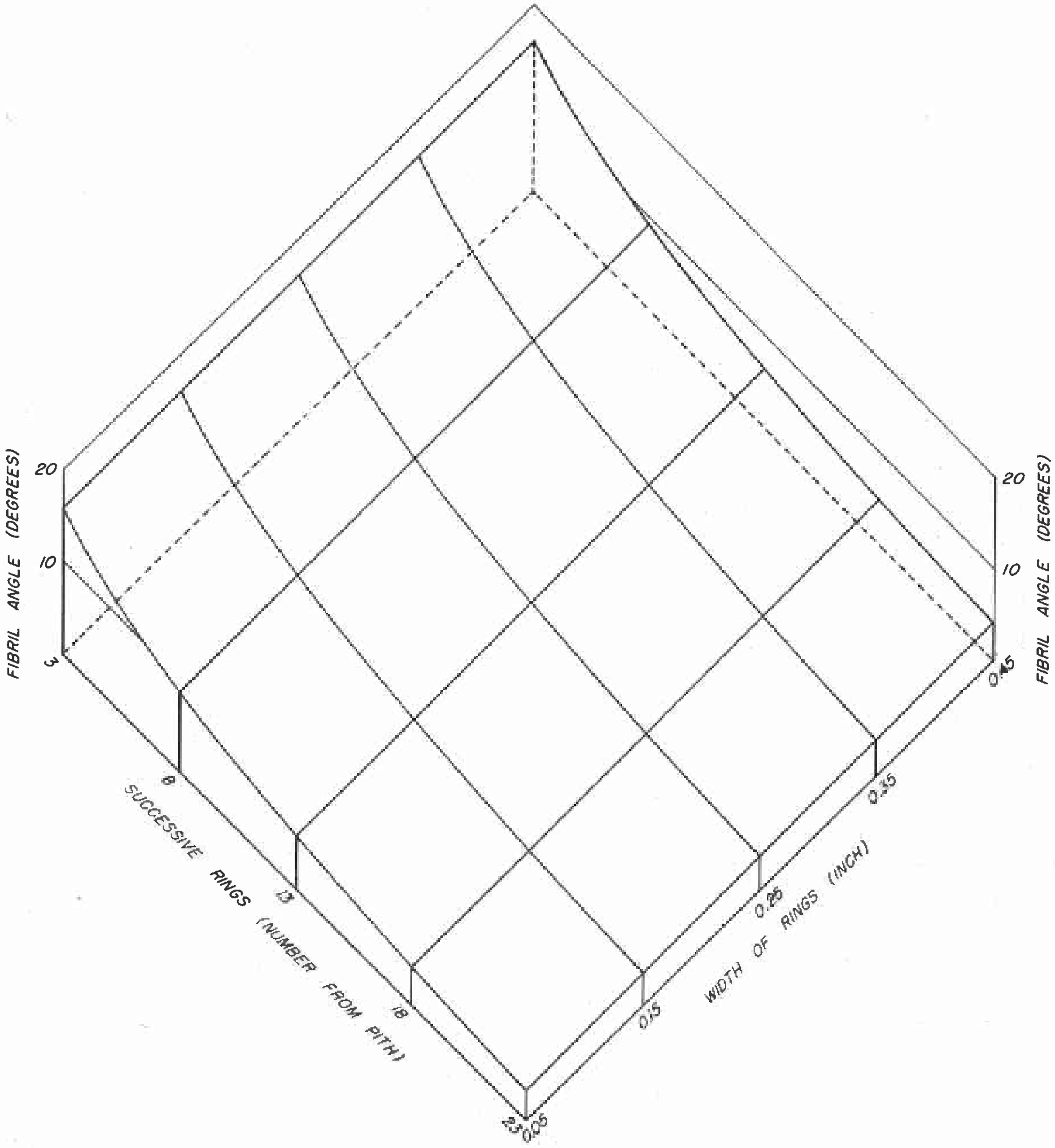

Figure 15. --Joint relations of fibril angles to the successive annual-ring number from the pith and the width of the rings at intermediate and crown heights in loblolly pine, 30 to 35 years old.

Z M 92309 F