

Professional Affairs

SPIRAL GRAIN IN *PINUS OOCARPA*

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ABSTRACT

Patterns of spiral grain in twenty trees of *Pinus oocarpa* Schiede growing in the central highlands of Honduras were examined. The mean slope of fibers in the stem was 4.1°, with a range from 0° to 16°. In 84% of the samples measured, grain deviation was right-handed. Left-handed deviations were observed in 10% of the samples and only 6% were straight-grained. Large among-tree differences in grain direction and magnitude were found, and within-tree variation was high in both radial and horizontal directions for most individuals. Notwithstanding the large variation, a general within-tree pattern of spiral grain was detected in the stem. The juvenile wood (rings 1–3) had small slopes and was dominantly inclined to the left throughout the stem. As ring number increased, the magnitude increased to maximum at rings 9–15, then gradually decreased throughout the stem. The only exception was at the base of the tree where slope increased steadily with ring number. Grain direction in the mature wood showed an increase in the proportion of right-hand grains as ring number increased and stem height decreased. No relationship was found between diameter growth rate and magnitude of slope. Spiral grain in the branches of these same trees showed a similar radial pattern, but no firm relationship between stem and branch grain could be discerned. Since 15% of the trees studied possessed excessive spiral grain, it was concluded that this defect substantially reduces the value of the lumber of *P. oocarpa*.

Keywords: *Pinus oocarpa*, spiral grain, interlocking grain.

INTRODUCTION

Spiral grain in wood refers to the angular arrangement of fibers in a tangential plane with reference to the pith or vertical tree axis. It is a common characteristic of almost all forest trees, and it has been suggested that spiral grain is the normal condition while straight-grained wood is a rare occurrence (Noskowiak 1963).

Spiral grain generally decreases the strength of the wood and causes problems in seasoning of lumber. Interlocking grain, a form of spiral grain, can have a serious effect on machining of lumber, and spiral grain in veneer produces splits or tears in the sheet. Many tree species have shown excessively high degrees of spiral grain (Zobel 1961; Gerischer and Kromhout 1964; Teissier du Cros et al. 1980). A large number of factors have been cited as probable causes of spiral grain (Champion 1924; Rao 1954; Preston 1949), but Nicholls (1963) stated that no generally acceptable theory has been found. The characteristic is apparently inherited (Smith 1967; Mikami et al. 1972; Teissier du Cros et al. 1980), but Zobel (1973) pointed out that much additional study is needed before the degree of genetic control can be verified.

One major problem concerns the complex and varied patterns that emerge

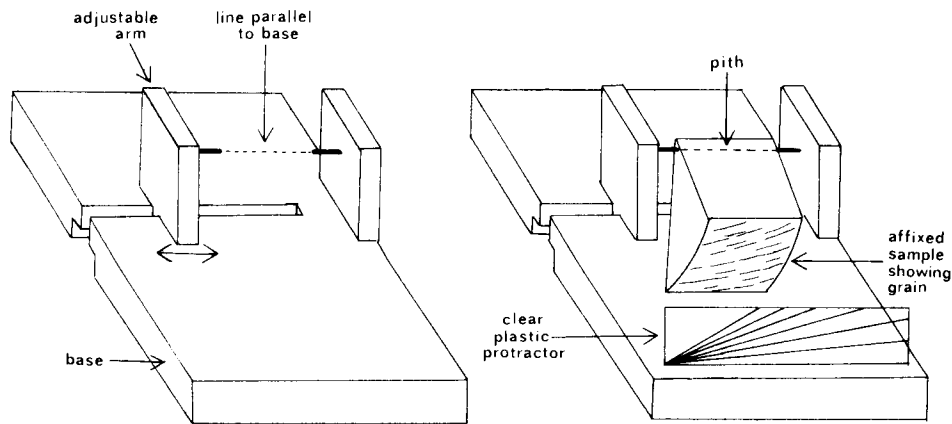


FIG. 1. Diagram of apparatus used in determining spiral grain.

when variation patterns are measured among and within trees. This has made it difficult to evaluate the effects of spiral grain on wood quality and has caused problems in comparing trees. Nevertheless, breeding programs have been proposed to improve the characteristic in several species (Gerischer and Kromhout 1964).

The presence of spiral grain in *P. oocarpa* is conspicuous in the outer wood of dead trees whose bark has been lost. The author has observed numerous standing and fallen dead trees that have exhibited varying degrees of left- and right-hand spiral grain. Villalobos and Sosa (1977) sampled disks at a height of 14 feet from 71 trees of *P. oocarpa*. Estimates of spiral grain were made near the pith, at the midpoint between the pith and the bark, and on the last-formed wood of each sample. The greatest mean angle was 7.4° found in the outermost sample, while the smallest mean angle of 3.9° was found closest to the pith. Much variation was found in the direction and magnitude of slope within and among trees.

The present study was initiated to provide basic information concerning the magnitude and pattern of spiral grain in *P. oocarpa*. This information will be used to decide whether this characteristic is economically important, and if so, will afford criteria for designing an adequate sampling system for its improvement.

MATERIAL AND METHODS

This study sampled spiral grain from twenty well-formed *P. oocarpa* trees distributed over a wide range of sites near Siguatepeque, Honduras (approximately $14^\circ 35'N$ and $87^\circ 48'W$). Average altitude of these sites is 1,100 m. Sample trees were separated by at least 100 m. The average tree age, calculated by ring count at the base, was 34.5 years, with a range of 29 to 62 years. The average diameter at breast height (dbh), was 36.3 cm, with a range of 27–41 cm.

The trees were felled at the base. A 5-cm-thick disk was removed from the basal section and every 1.5 m up the stem thereafter. From three to five branches were sampled from nineteen of the subject trees at varying heights by removing a 5-cm-thick disk at a distance of 10 cm from the main stem. From each disk, both stem and branch, a pie-shaped wedge was removed, which included the

pith. The wedge was sampled from a section of the disk that did not show evidence of compression wood nor the effect of closely occurring branches. On stem samples, the first and third and every third annual growth ring to the bark thereafter, including the outermost one, was designated for measurement, and its distance from the pith was measured to the nearest 0.1 cm. Because of the difficulty in distinguishing and separating annual rings in the branchwood, only three samples were designated for examination: the first was "near" the pith, the second from the central portion of the radial section, and the third from the outermost growth ring.

In order to determine the angle and direction of the grain, a simple apparatus was improvised (Fig. 1). The apparatus consists of a viselike affair on which are mounted two pins that align perfectly and form a line exactly parallel to the upper surface of the base of the vise. Each sample was attached by moving the adjustable arm so that the pith on either side was affixed on one of the two pins. Thus with the aid of a clear plastic protractor and using the pith as the longitudinal reference axis, the angle and direction of the grain of each sample were determined to the nearest degree of arc.

The process of measuring the spiral grain consisted of first clamping the wedge in the vise and measuring the outermost annual ring. The wedge was then removed from the vise, and with the aid of a wood chisel, the outer rings were removed down to the next designated ring and measurement was repeated. The process was thus repeated to ring number one. In each case, the last-formed latewood of each ring was measured.

RESULTS

Among-tree variation in the stem

Of a total of 2,308 observations of spiral grain in the stem, 84% were left-handed, 10% were right-handed, and only 6% presented straight grain. *P. oocarpa* has a strong tendency to spiral to the left, which is in accordance with findings for most pine species, especially at younger ages (Noskowiak 1963). The magnitude of the slope for all observations ranged from 0° to 16°, with a mean of 4.1°. Gerischer and Kromhout (1964) found the mean spirality for *Pinus patula*, *Pinus taeda*, and *Pinus elliottii* grown in South Africa to vary from about 2.0° to 2.5°. By comparison, *P. oocarpa* has relatively high spiral grain values.

Table 1 presents grain direction and slope values on an individual tree basis. The majority of the trees were predominantly spiraled to the left, with fourteen of the twenty trees showing 10% or less of their observations inclined to the right. Of the trees showing some tendency toward right-hand grain only two trees, 1 and 14, contained unusually large percentages. A relationship between the percent of right-hand observations and magnitude of slope is seen wherein an increase in the proportion of right-hand observations corresponds to a decrease in mean angle. This suggestion is supported by a highly significant negative correlation coefficient of -0.59^{**} when these two parameters are compared.

The mean slope varied greatly among the individuals and ranged from 1.9° to 8.1°. This degree of heterogeneity confirms that *P. oocarpa* is highly variable in the expressions of spiral grain. Table 1 shows that trees 5, 7, and 18 have mean slopes of 6.8° or greater. These same three trees demonstrated consistently large slopes, where at least 66% of their observations had a minimum slope of 6°.

TABLE 1. *Individual tree mean slope and direction values.*

Tree no.	No. of observ.	Grain direction			Slope		
		% left	% right	% straight	Mean (degrees)	Standard deviation	% observ. $\geq 6^\circ$
1	215	54	33	13	1.9	1.6	3.7
2	78	82	5	13	3.2	2.1	16.7
3	106	97	0	3	4.6	2.5	38.7
4	123	67	14	19	3.3	2.8	17.1
5	97	100	0	0	6.9	2.6	66.0
6	99	92	2	6	3.5	2.3	15.1
7	97	98	0	2	8.1	3.0	81.4
8	146	82	12	6	3.8	2.3	22.6
9	118	86	10	4	3.6	1.9	13.6
10	103	80	15	5	2.8	1.3	2.9
11	226	88	8	4	4.0	1.9	20.3
12	113	99	0	1	5.1	2.2	39.8
13	102	88	9	3	4.1	3.4	10.8
14	98	50	34	16	3.8	1.8	0.0
15	103	89	6	5	3.0	1.6	2.9
16	106	98	1	1	4.1	1.9	23.6
17	96	85	12	3	3.9	1.8	15.6
18	102	100	0	0	6.8	2.4	68.6
19	92	92	1	7	3.0	1.6	8.7
20	88	89	6	5	4.6	2.7	38.6

The data presented thus far give a clear impression of the aggregate spiral grain for each tree. However, the large standard deviations of the means of the individuals indicate that the grain varies substantially within the stem.

Radial variation in the stem

Figure 2 shows some of the variation in spiral grain found when moving from the pith outwards in four different trees at 1.5 m. Tree 7 shows a uniform left grain, while tree 1 shows a dominant right grain. Trees 17 and 11 demonstrate varying degrees of interlocked grain. These patterns were not consistent when moving up or down the stem in the same tree. Since radial grain patterns are so variable within a single tree and between individual trees, it is difficult to form generalizations about variation patterns. However, comparisons of mean values of all observations in relation to ring number could yield useful information.

In Table 2 the percentage of right-hand observations and mean slope in relation to ring number for all trees at all heights is presented. A definite pattern of increasing inclination to the right is observed when moving outward from the pith. This relationship is confirmed by a highly significant correlation coefficient of 0.76**. The mean slope values are also related to ring number and, in this instance, slope increases steadily from the pith until a maximum is reached at 15 years of age, followed by a gradual decrease in the outer rings.

Vertical variation in the stem

Spiral grain varied considerably when comparing vertical patterns among trees at the same ring and within trees at different rings. For example, Fig. 3 shows vertical variation patterns at the twelfth ring from the pith for three trees. It was

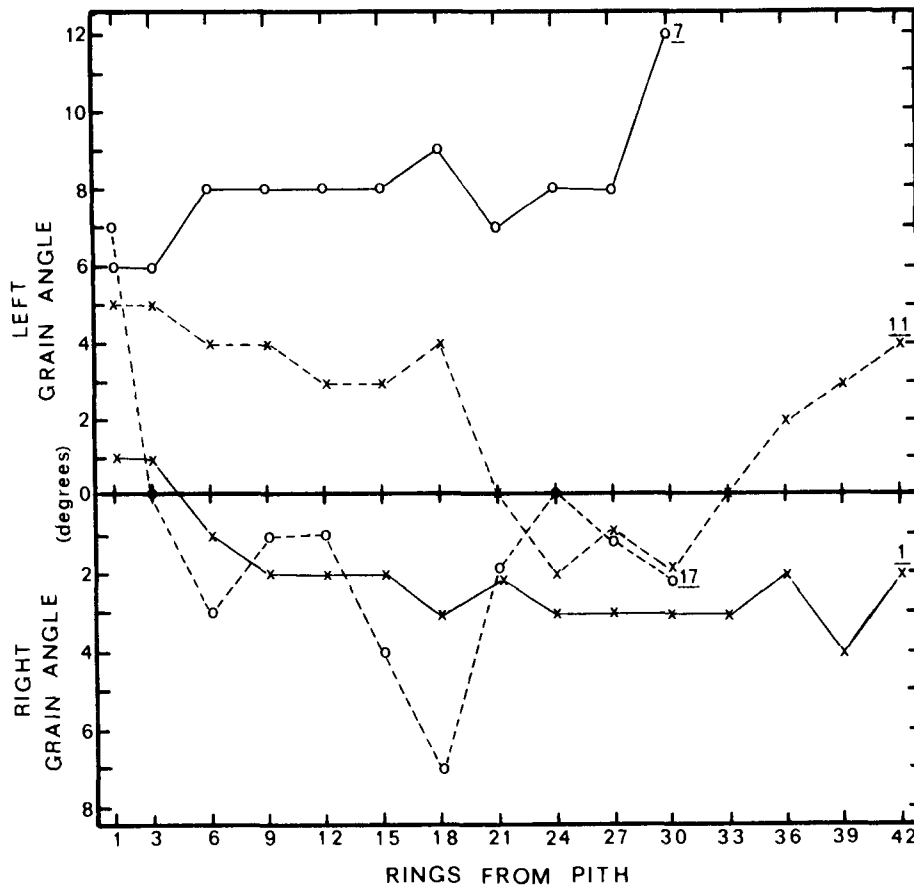


FIG. 2. Comparison of the radial pattern of spiral grain in four trees at 1.5 m.

felt that the examination of mean values would make the generalization of these patterns possible.

Table 3 presents the percent of right-hand observations and mean slopes as related to height for all trees and ring numbers. The greatest amount of right-hand grain occurs at the base of the tree and is relatively high throughout the first three meters. As height increases, a fairly consistent decrease in right-hand grain occurs, which is confirmed by a highly significant negative correlation coefficient of -0.81^{**} . Variation in the magnitude of inclination with respect to height showed no distinct pattern. This finding is contrary to the general case where Nicholls (1963) states that for most trees the magnitude increases with height.

The vertical variation demonstrated in Table 3 may be influenced by the age of the wood included in each vertical sample. Therefore, vertical variation within a single year of secondary growth was examined. Figure 4 shows the vertical spiral grain pattern found in the outermost ring of three sample trees. Significant changes in both the magnitude and direction of the grain with respect to height are clearly visible within each tree. All trees showed some evidence of this. One

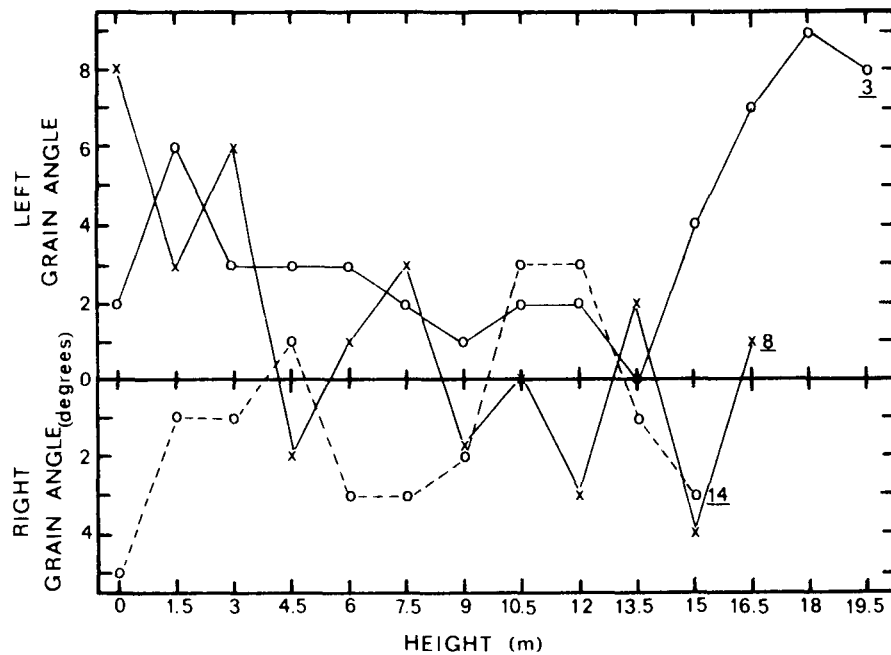


FIG. 3. Comparison of the vertical pattern of spiral grain in the 12th ring from the pith of three trees.

might expect to find a change in grain upon entering the live crown because of hormonal and/or physiological differences; however, variation in the lower stem (i.e. below 10 m) would be expected to be small. The reason for the high degree of variation encountered in this case is not clear. Nicholls (1963) found that there was some variation in grain angle, which was related to the position within a single internode in the same ring when *Pinus radiata* was examined. However, the variation throughout the internode was small and would not explain the excessive variation found here.

TABLE 2. Grain direction and slope as related to ring number.

Ring no.	% right-hand observations	Mean slope (degrees)
1	2.4	3.4
3	2.0	3.9
6	3.6	4.2
9	5.7	4.3
12	8.0	4.3
15	8.3	4.4
18	9.6	4.2
21	10.8	4.1
24	18.0	4.1
27	16.7	4.0
30	26.4	3.5
33	21.6	3.4

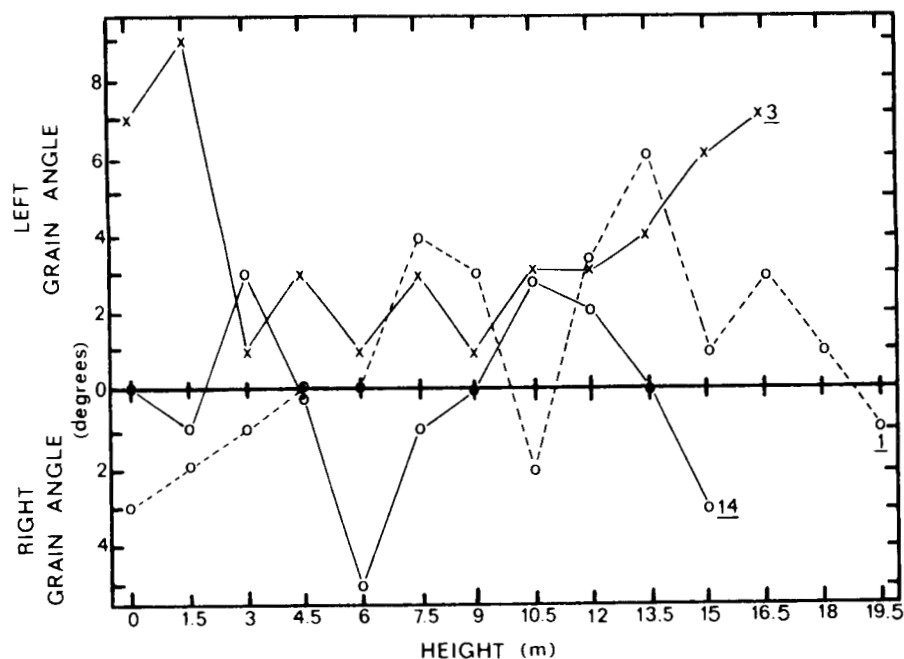


FIG. 4. Comparison of the vertical pattern of spiral grain in the outermost ring of three trees.

The pictorialized scatter diagram in Fig. 5 summarizes the vertical and horizontal variation patterns found in spiral grain in the stem of *P. oocarpa*. Each point corresponds to a particular height and ring number and, in the case of slope, is the mean of the twenty trees, while in the case of direction is the percentage of trees that have slopes inclined to the right. By combining Fig. 5 with the information thus far presented, a general pattern of spiral grain in the stem of *P. oocarpa* can be developed. The juvenile wood (rings 1–3) has small slopes and is dominantly inclined to the left throughout the stem. As the ring number increases, the magnitude increases to a maximum around rings 9–15 and gradually

TABLE 3. Grain direction and slope as related to stem height.

Height (m)	% right-hand observations	Mean slope (degrees)
0	20.7	4.2
1.5	15.3	4.0
3.0	11.2	5.3
4.5	6.3	4.0
6.0	15.0	4.1
7.5	5.2	4.1
9.0	6.0	4.1
10.5	11.8	3.6
12.0	3.7	3.9
13.5	2.0	4.3
15.0	5.6	3.9
16.5	1.0	4.2

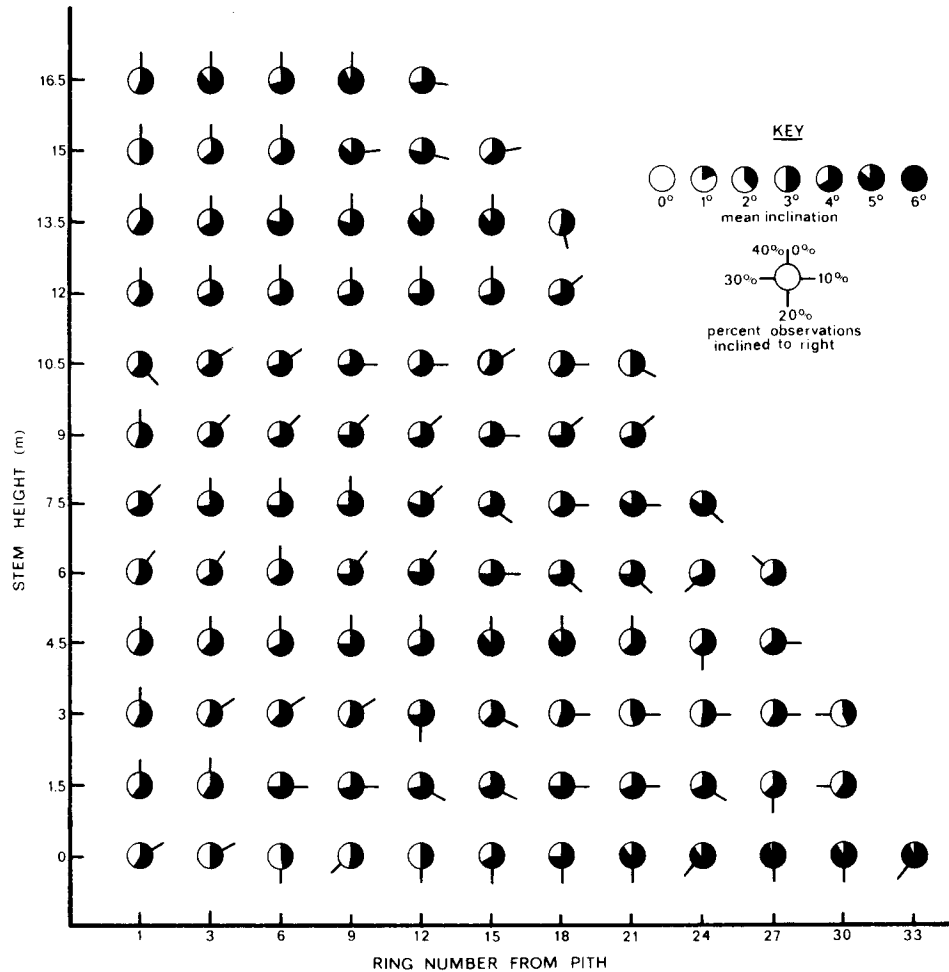


FIG. 5. Scatter diagram depicting the mean within-tree pattern of spiral grain.

decreases thereafter throughout the stem. The only exception is at the base of the tree, where slope increases steadily with ring number. Grain direction in the mature wood zone shows an increase in the proportion of right-hand grains as ring number increases and stem height decreases. This pattern is in accordance with the general pattern described for conifers (Noskowiak 1963).

Variation in the branches

Of the 231 branch observations, 30% were right-handed, 6% were straight-grained, and 64% were left-handed. The large percentage of right-hand observations found in the branches is three times greater than that found in the stem. The mean magnitude was 3.3° , with a range from 0° to 15° , which is somewhat less than the 4.1° mean found in the stem.

A radial pattern of spiral grain direction was found where the overall percent of right-hand observations increases from 6% to 23% to 61% of the total as the

sampling point moves from the center through the outer sections of the branch. Although a similar pattern exists in the stem, the right-hand tendency in the outer sections of the branches is much stronger. The mean slope varied from 3.2° to 2.6° to 4.0° when moving from the center outwards, which is contrary to the pattern found in the stem.

No apparent relationship exists between the branch and stem spiral grain. Some trees tended to maintain a similar grain direction as in the case of tree 3, where all stem and branch slopes were inclined to the left. On the other hand, tree 18 had all left-hand grain in the stem but produced 42% right-hand grain in its branches. In terms of the magnitude, the relationship between the stem and branches was again undiscernible. For example, trees 5 and 7, which had the greatest mean slopes in the stem, showed low mean branch values. No relationship was noted as to either the angle or direction of the spiral grain in branches with relation to their height up the stem.

Effect of diameter growth

The review by Noskowiak (1963) cites numerous examples of strong associations between diameter growth rate and the magnitude of spiral grain. The relationship was examined here by performing two correlation analyses. In the first case, the mean diameter growth rate for each sample tree, expressed as the quotient of its dbh divided by its age, was compared to its mean slope. In the second case, the basal area of the outermost growth ring of each tree was compared to that ring's slope. In both instances, the correlations were insignificant.

DISCUSSION AND CONCLUSIONS

The twenty trees examined in this study all expressed some measure of spiral grain. The overall mean slope for all trees was 4.1°, which is high when compared to other pines (Gerischer and Kromhout 1964). Moreover, individual tree means ranged to 8.1°, with individual measurements reaching 16°. The question is, are these values excessive and do they actually lower wood strength and quality to a substantial degree? The strict and direct evaluation of mean spirality is difficult. The Wood Handbook (1974) shows that wood with a 1 in 10 slope (approximately 11°) has strength characteristics of 81% for the modulus of rupture and only 62% for impact bending compared to that of straight-grained wood. Noskowiak¹ states that a 7° slope reduces overall strength of the wood by 20%. Teissier du Cros et al. (1980) set acceptable limits for beech (*Fagus sylvatica*) at 10° for saw timber and 6° for veneer. These examples are all based on the assumption of constant slope and direction. *P. oocarpa* has proven to be extremely variable in its within-tree spiral grain. The effect of such fluctuations in slope and/or direction in a limited section of wood has not been sufficiently studied. However, it is logical to assume that large local changes in slope will create additional internal stresses in the wood. Furthermore, radical changes in direction of grain result in interlocking grain, which has serious effects on mechanical properties and machining

¹ Personal communication from Dr. Arthur Noskowiak, College of Forestry Washington State University, Pullman, Washington.

characteristics. By weighing the effects of uniform spiral grain and its probable interaction with deviations in magnitude and slope, a mean slope of approximately 7° is considered to be a realistic upper limit for acceptable spiral grain. Using this criteria, 15% of the trees examined in this study show unacceptable levels of spiral grain. It is therefore concluded that spiral grain is a serious defect in natural populations of *P. oocarpa* and that a potential problem exists in the effective utilization of its lumber.

Spiral grain proved to be a complex character in *P. oocarpa*. It is the amalgum of two distinct traits, magnitude and direction, and it varied greatly among and within the trees sampled. The high among-tree variation may present a good opportunity for its genetic improvement through selection. Several studies on other species have shown the trait to be moderately heritable (Smith 1967; Makami et al. 1972; Teissier du Cros et al. 1980); and if this is true in *P. oocarpa*, substantial gains can be predicted following mass selection. However, it must be pointed out that if it is heritable, only a complex genetic system could account for the large amount of within-tree variation. It is clear that much additional investigation is needed before the character will be fully understood.

On a more practical level, the selection criteria for spiral grain must be clarified before routine screening can begin. The 7° limit proposed earlier is a rough estimate at best, and it is evident that a thorough understanding of the effects of complex patterns of spiral grain on wood strength and quality is essential in order to produce a reliable criteria. Associated with this concept is the need to design an accurate system for sampling whole tree spiral grain. Since within-tree variation is high, whole tree estimates based on one or two measurements would be unsatisfactory, and multiple measurements would be needed. Correlation analysis comparing the mean slope of all rings sampled at 1.5 m for each tree with the whole tree mean slope resulted in a highly significant coefficient of 0.90**. This suggests that a single sample taken at breast height and including a broad array of annual rings would produce a good estimate. A microscopic technique developed by Naskowiak (1968) using increment cores could be used to make the desired measurements without damaging the tree.

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