SPIRAL GRAIN PATTERNS IN PLANTATION-GROWN *PINUS RADIATA*

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ABSTRACT

Spiral grain measurements were made on wood disc samples from fifty 25-year-old trees of *Pinus radiata* D. Don grown in Kaingaroa Forest in the central North Island of New Zealand. Strong radial and vertical patterns were established, but there was also a major individual tree effect. The most pronounced deviations from vertical grain were in the inner 10 growth rings (corewood zone), where the left-hand angles averaged 4.7°. This amount of deviation is sufficient to cause significant problems in processing and marketing through drying degrade, strength loss, and movement in service. Outside this zone, angles were generally less and showed a higher proportion of right-hand spirals.

The high average corewood spiral grain and the degree of variability between trees reinforce the possibility of a strong genetic component and point to the need for a more efficient sampling method. Statistical analyses of the grain measurements indicated that there are large errors associated with predicting tree values from single ring assessments. It is feasible, however, to compare groups of trees (treatments, families, clones) using a relatively small number of ring measurements.

Keywords: spiral grain; corewood; *Pinus radiata*.

INTRODUCTION

Spiral grain (alignment of the tracheids at an angle to the stem axis) occurs widely as a natural feature of standing trees, but is most readily observed in the checks which appear along the grain in dead trees and dry poles. The direction of the spiral is often highly variable, but the technical consequences of grain deviations in solid wood products are well documented; the most important are the loss in strength properties and the dimensional instability associated with changing moisture content.

The recent review of research on spiral grain by Harris (1989) emphasised the great variation in the occurrence of grain patterns, both between and within tree species, and highlighted the lack of success in understanding the fundamental causes of the phenomenon. In old trees from natural forests the greatest grain angles are commonly found near the outside of the trees. McBride (1967) documented a case in British Columbia where about 7% of *Pseudotsuga menziesii* (Mirb.) Franco (Douglas fir) logs and 2% of *Tsuga heterophylla*

(Raf.) Sarg. (hemlock) were degraded owing to visible spiral grain. In plantation crops, the greatest expression is usually in the juvenile wood region and not normally apparent from the external appearance of mature trees.

Spiral grain in *Pinus radiata* (radiata pine) has been identified in the past as a potential problem in wood processing, and research has been reported on measurement methods (Harris 1984), causes (Harris 1973), effects of silviculture (Cown & McConchie 1981), and effects on timber distortion (Mishiro & Booker 1988). However, the variation of spirality in *P. radiata* has not often been described in terms of within- and between-tree patterns. Harris (1991) described a "typical" pattern for 35-year-old stems as follows:

> "In radiata pine, tracheids immediately adjacent to the pith are closely aligned with the stem axis, deviating only around needle traces, but with further stem growth tracheids become more or less spirally aligned (always to the left), usually reaching a maximum angle to the vertical by completion of the second or third annual growth layer. After reaching its maximum, the grain angle decreases slowly and usually approaches zero (i.e., the wood becomes straight grained) by about the ninth growth layer, beyond which small grain angles, seldom exceeding 2°, may occur either to the left or the right. Thus spiral grain in radiata pine is essentially a feature of the central zone of wood surrounding the pith, and is seldom severe outside the first six or so annual growth layers. In this respect, radiata pine differs from many of the slower growing commercial softwoods of the Northern Hemisphere in which spiral grain is predominantly a feature of the outerwood of old trees."

Fielding (1967) described similar trends for *P. radiata* in Australia and suggested that trees tended to have characteristic patterns. This enabled him to conclude that measurements taken at the outer surface of the stem could serve as an indicator to internal grain angles. This concept was developed further by Harris (1984) who devised a simple field tool to mark the outerwood grain angle relative to the vertical axis of the tree and then extract 12-mm increment cores for growth ring assessments.

The reported pattern for *P. radiata* is also dramatically different from that found in plantation *Pinus caribaea* Morelet grown in Fiji. No consistent pattern was found and grain angles could only be described as highly variable and unpredictable both within and between trees (Cown *et al.* 1983).

Genetic selection for growth rate and intensive management of *P. radiata* plantations in New Zealand have made it possible to produce stems of merchantable size at ages between 20 and 30 years. Previous research on these stands has highlighted the effect of reducing the rotation age on the basic properties of the wood. For instance, the relationships between age and basic density, moisture content, and heartwood formation have been documented (Cown & McConchie 1982). It has become apparent in recent sawing and drying research that timber from young fast-grown stands may be more prone to drying degrade, predominantly twist, as a result of the higher percentage of boards with spiral grain (Haslett & McConchie 1986). The study reported here was part of an investigation into the impact of crop characteristics on timber quality and included the following objectives:

(1) To exhaustively measure a large number of mature trees to establish clearly the within- and between-tree patterns of spiral grain variation;

(2) To investigate the feasibility of deriving a standard non-destructive measure for "average" tree spiral grain.

METHODS AND MATERIALS

A 26-year-old stand of *P. radiata* growing in Kaingaroa Forest had been selected as "typical" of the crops coming due for harvest in the next 5 years (Table 1). Fifty trees were selected to provide logs for a sawing study of "new crop" *P. radiata*, and these were used as a source of material for an assessment of spiral grain.

TABLE 1–History of sample stand

Date	Operation	Stocking (stems/ha)
1965	Established	2500
1968	Waste thinned	1320
1971	Low pruned to 2.2 m (360 stems/ha)	
1972	Waste thinned	690
1973	Medium pruned to 4.0 m (260 stems/ha)	
1974	High pruned to 5.8 m (275 stems/ha)	
1975	Waste thinned	350

The sample trees were selected to provide logs representing a range of log and branch sizes, as described in the log grades proposed by Whiteside & Manley (1987).

Wood discs were collected from each stem, at the butt and at the top of each subsequent sawlog length (5.5 m). The 50-mm-thick discs were assessed for a range of wood properties. Spiral grain was measured using the axis of the disc as the reference, according to the method described by Brazier (1965). Each growth ring was assessed across a predetermined diameter by exposing the latewood with a chisel and scribing along the grain direction with a "grain detector" (Harris 1989). Grain angle was measured in relation to the upper surface of the disc. By measuring along two opposite radii in this way, any deviation of the disc axis from the "true" horizontal plane is compensated for and a good average grain angle obtained.

Since only limited information exists on the within- and between-tree patterns of spiral grain in *P. radiata*, an extensive assessment was performed on the discs from 10 trees. Each individual ring was measured in all discs to give a full picture of the variation radially and vertically. This is a time-consuming procedure, and it was theorised that if consistent patterns were the norm, the amount of work required to assess trees or samples in future could be reduced. On the basis of this initial information a more efficient sampling scheme was devised for the remaining trees.

RESULTS

Preliminary Sample

The combined data for Trees 1 to 10 are given in Fig. 1, with each value representing the average of 10 readings. The overall trends were clear, and so analyses were performed to evaluate the amount of data required to determine these patterns and provide good comparisons between groups of trees, e.g., seedlots or different silvicultural treatments.

From this it was decided that a measure of every second growth ring would be adequate (Fig. 2). This was the procedure adopted for the remaining 40 trees, thus reducing the work by 50%.

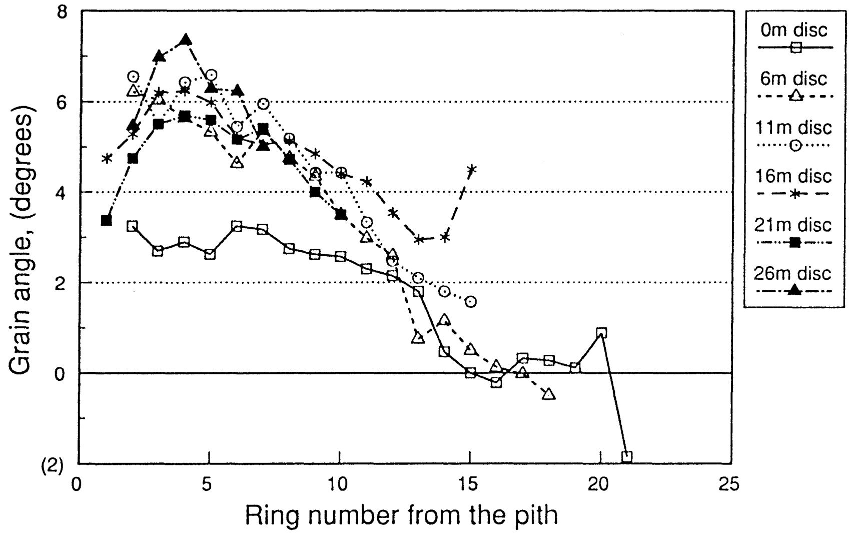

FIG. 1–Mean grain angles for Trees 1–10 (all rings).

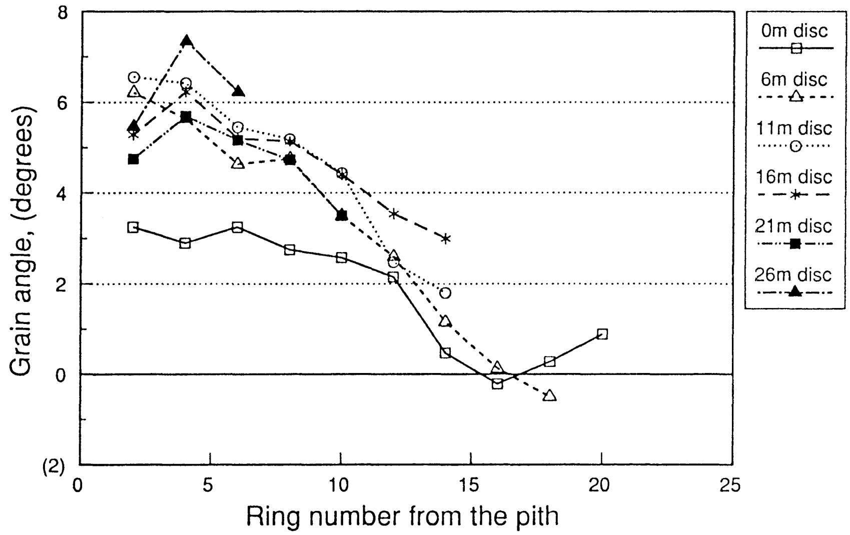

FIG. 2–Mean grain angles for Trees 1–10 (every second ring).

Within-tree Spiral Grain Pattern

Average trends for the combined data (50 trees) are given in Fig. 3. At all stem levels there was a general decrease in grain angle with cambial age from the pith to the bark. Omitting the measurement from growth ring No. 1 (as in Fig. 3 *v*. Fig. 1) disguised the tendency for straighter grain next to the pith (Harris 1965). However, the practical significance of this phenomenon is negligible, considering the very small volume of wood concerned.

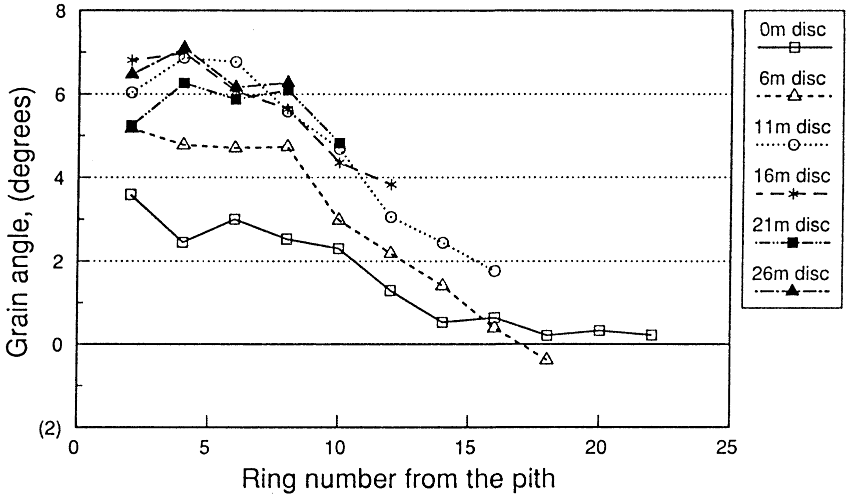

FIG. 3–Mean grain angles for all trees.

Of interest was the significant increase in grain angle with height in the stem. The difference between the butt level and 6 m was particularly prominent and raises the question of the validity of samples from the breast height position (1.4 m). This could not be investigated in this study as all logs were required for a sawing trial. Above the 6-m level changes were less marked but there was nevertheless a trend to further increases with height. Other research is now under way to establish (a) the relationship of grain angles at 1.4 m to those at the butt and 6 m, and (b) the prospects for non-destructive sampling using 5-mm increment cores.

All the observations conform very well to the normal distribution (Fig. 4), with a mean of 4.5° and a range from –7° to +18°. Only 14% were recorded as negative (RH) angles. It is difficult to get a clear measure of the relative severity of such angles, but it is interesting to note that the distribution is almost identical to that given by Nakagawa (1986) for *Pinus densiflora* Sieb. et. Zucc. grown in Japan, which is known to give problems with twist on drying.

Between-tree Variation

Tree mean grain angles averaged about 4°, with a standard deviation of 1.8 and a range of 0° to 8°. Individual ring data for trees 1 to 10 are given in Fig. 5. Several features emerge:

(1) The general trend of decreasing spiral grain angles from the centre of the stem outwards held for most trees, and in virtually all trees the angle was positive (left hand) in the first 10 rings from the pith.

(2) The vertical patterns were much less clear, and in fact showed little consistency on an individual tree basis. The butt level in particular was highly variable.

(3) Despite the large variations often evident between different levels in the stems, there was a strong tendency for some trees to have "high" values (e.g., Tree No. 49 with angles mostly between 5° and 15°) and some to have lower values (Tree No. 37 with angles generally between –5° and +5°) (Fig. 6). This lends weight to the suggestion of a strong genetic component (Harris 1965).

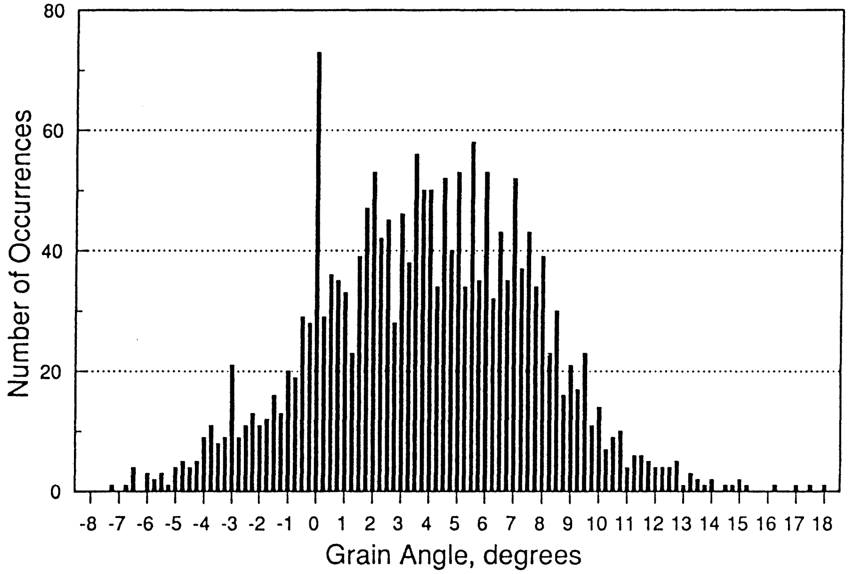

FIG. 4–Grain angle frequency distribution.

Statistical Analyses

An analysis of variance (ANOVA) was performed on the spiral grain measurements to test the relative effects of tree, sample height, and growth ring position (Table 2).

All sources were significant at the 1% level. The greatest variation was explained by disc and ring numbers, confirming that both height in the tree and distance from the pith greatly affect the observed spirality. The interaction of disc and ring numbers was much less significant.

Clearly, the variation in spiral grain is strongly related to both height in the tree and ring number from the pith, and hence the age of the trees at the time of sampling will have a strong effect on the observations. For the purpose of classifying stem spirality it is desirable to have a measure which is independent of sample age. The function used was the mean angle of the inner 10 growth rings, averaged over the discs from the butt to the 15-m level. This represents the corewood region in the main sawlog portion of *P. radiata* trees, and is hence the zone most likely to be troublesome in processing. Corewood values averaged 4.7° with a range of 0.6° to 9.3°. Correlations were derived between corewood spiral grain and individual ring measurements (Table 3).

The most significant correlations generally occurred using rings between 6 and 10 from the pith and at the 10-m height in the tree. Regressions developed to predict corewood spiral grain from single ring measurements showed the intercept value to be insignificant. This enables single ring values to be converted to corewood value using a simple multiplier (Table 4).

The range of corewood values (0.6 to 9.3) is such that a measurement technique, to be useful, should have a standard error of no more than 1.0, and preferably 0.5. This is

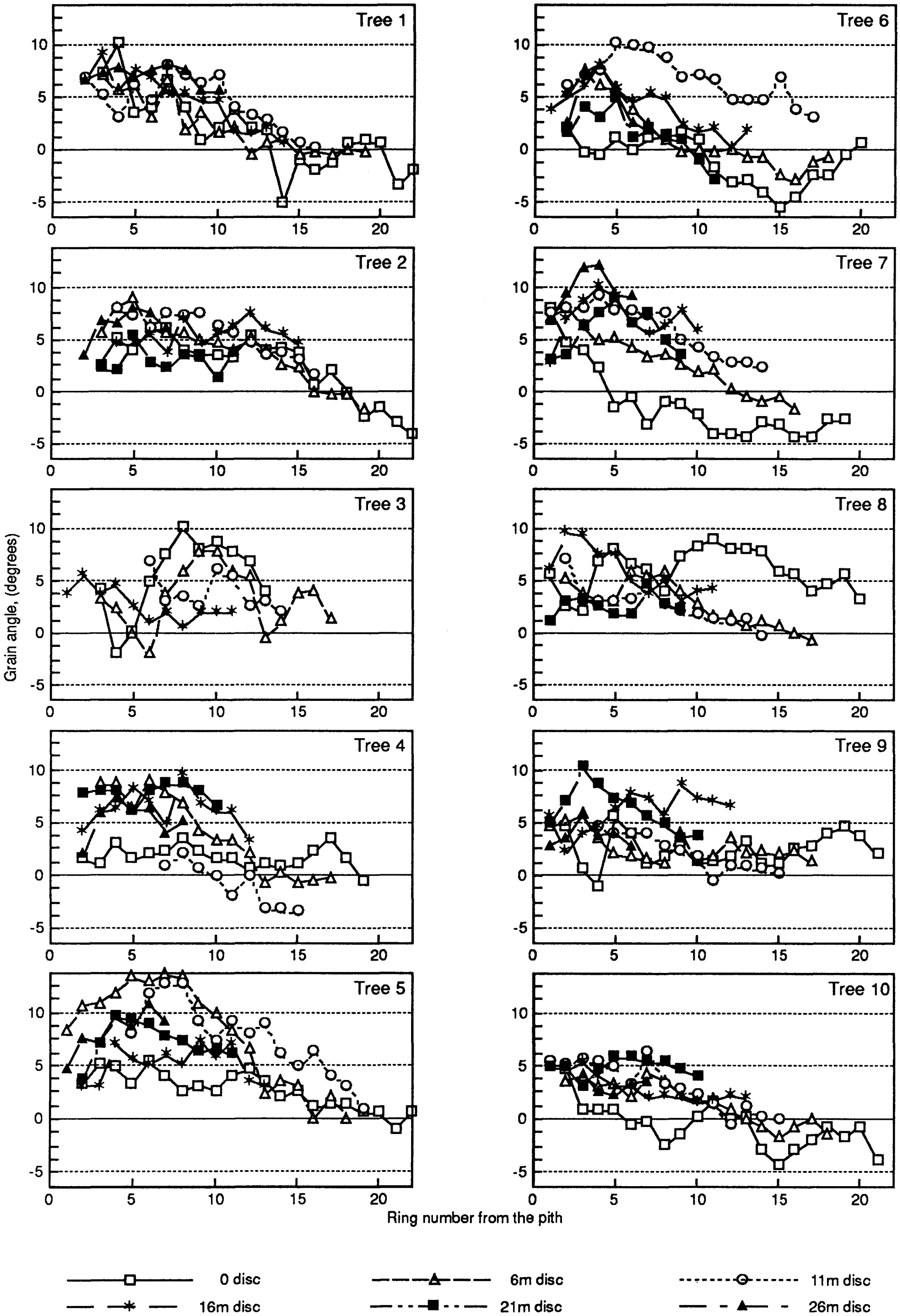

FIG. 5–Grain angles for Trees 1–10.

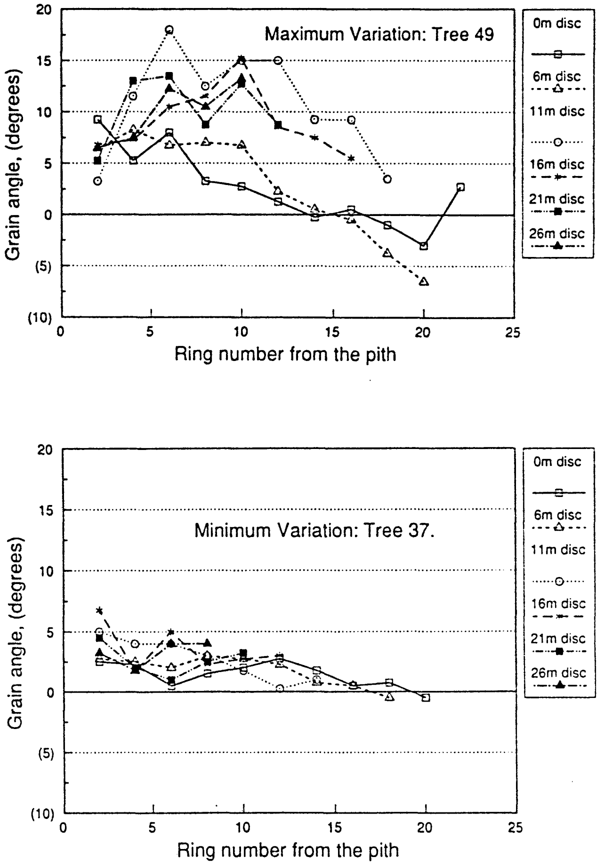

FIG. 6–Variation in grain angles within trees.

TABLE 2–ANOVA Sources of variation in spiral grain

Source	d.f.	Mean square	F-value
Tree	49	120	16.7**
Disc	5	398	55.5**
Ring	10	316	44.0**
Disc × Ring	28	16	2.2**
Error	1816	7	

** Significant at the 1% level.

impossible with a single measurement (Table 4), but may be approached by taking several measurements at different heights if samples are available. However, this is not very practical.

In general, means of groups are of more interest than single phenotypic spiral grain assessments. The results suggest that single measurements can provide adequate accuracy in such situations. For example, the measurement error of the mean of 25 trees (e.g., a family or clone) will be 20% that of the single tree values in Table 4.

TABLE 3–Correlations between corewood grain angles and individual rings

Ring No.	Butt	5 m	10 m	15 m	20 m	25 m
2	0.28	0.47	0.61	0.50	0.18	0.55
4	0.43	0.48	0.77	0.68	0.40	0.67
6	0.65	0.59	0.78	0.55	0.40	0.58
8	0.50	0.68	0.83	0.67	0.56	0.77
10	0.41	0.64	0.88	0.71	0.39	–
12	0.44	0.45	0.81	0.64	–	–
14	0.35	0.46	0.67	0.62	–	–
16	0.38	0.21	0.69	–	–	–
18	0.44	–0.07	–	–	–	–
20	0.28	–	–	–	–	–
22	0.28	–	–	–	–	–

TABLE 4–Multipliers for predicting corewood grain angle

Disc	Ring No.	Multiplier	Standard error
Butt	4	1.79	6.0
	6	1.48	3.3
	8	1.76	4.7
	10	2.01	5.2
	12	2.89	9.6
5 m	4	1.03	3.2
	6	1.04	2.7
	8	1.01	2.2
	10	1.48	3.5
	12	1.97	5.2
10 m	4	0.69	1.7
	6	0.70	1.6
	8	0.81	1.8
	10	0.92	2.1
	12	1.31	3.3
Butt		1.65	3.2
Butt, 5 m	8	1.28	2.2
Butt, 5 m, 10 m	8	1.07	1.3

DISCUSSION

It is surprising that so little is published on spiral grain in *P. radiata* in view of the relatively high angles recorded in the corewood and its potential impact on utilisation (O'Hara & Grant 1985). Although a weighted average was not calculated for the timber in the study, the disc assessment indicated a median value of 4° to 5°. In contrast, Zobel *et al.* (1968) found values of around 2° in the corewood of *Pinus taeda* L. and concluded that spiral grain would not be a problem in that species. The fact that southern pines can be dried in a high-temperature kiln without the stack restraint necessary with *P. radiata* confirms this.

The reasons for the high degree of spirality in *P. radiata* are not known, although there is some evidence that fast growth can by itself encourage greater grain deviation. This has not yet been conclusively demonstrated for *P. radiata*.

The patterns of spiral grain variation determined for 25-year-old *P. radiata* in this study conform, in general terms, to those described previously by Chattaway (1959) and Harris (1965). The sample size in this study (50 trees) is sufficiently large to give reassurance that the patterns are real.

While it may be true, as Harris (1989) stated, that the maximum grain angle occurs between the third and fifth growth rings from the pith, the data reported here indicate that the drop off is more gradual than previously suggested, and that in fact the "zero angle" situation does not occur until about 15 rings from the pith. The average pattern for the 50 trees sampled in this study showed that angles in excess of 5° are frequently maintained within the first 10 growth rings from the pith. Detailed analysis of the sawn timber from the study logs showed that 5° is a critical level, above which significant twist (sufficient to downgrade the timber according to the New Zealand Timber Grading Rules – NZS 3631:1990) is very likely, even with the appropriate restraint during drying (A.N. Haslett, pers. comm.).

This adds further weight to the arbitrary decision, based on wood density levels, to consider the inner 10 rings as the "juvenile wood" or "corewood" zone for *P. radiata* grown in New Zealand.

Both research results and commercial practice in New Zealand and Australia have shown the necessity to use stack restraint in high-temperature drying of timber containing juvenile wood (Williams & Kininmonth 1984). The preponderance of this type of wood in short-rotation crops is clearly one of the reasons spiral grain is likely to be an increasingly significant feature of *P. radiata* and raises the question of whether the situation can be altered. In the short term, incremental gains can be made through better knowledge of the phenomenon and improvements in conversion and drying practice. In the longer term, there is a strong possibility of genetic manipulation.

The results of this study indicate that corewood values of tree groups can be predicted from assessments of single rings. Unfortunately, the samples from this study did not include breast height discs, so it is not yet possible to derive functions to predict tree values from breast height assessments.

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