IS SPIRAL GRAIN THE NORMAL GROWTH PATTERN ? ¹

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INTRODUCTION

For several years it has been the author's opinion that spiral grain in trees is the normal condition of growth and not the abnormality which timber users and foresters have frequently considered it to be. This opinion was derived from observations made when logging, milling, and cruising timber in British Columbia, and has been substantiated by records compiled during the past seven years at the Vancouver Forest Products Laboratory.

Spiral grain has frequently been observed in the logs and lumber of indigenous softwood species, in old snags, and in small saplings. In 1949 a stand of Engelmann spruce was observed in which 50 per cent of the trees were spiralled more than the 1 in 10 (5.7°) allowed by lumber grading rules and the remainder was spiralled less than this amount. Few, if any, of the trees were straight-grained. Apart from the spiral grain and mortality this was a particularly impressive stand of timber with trees up to four feet D.B.H. and upwards of 500 years of age. A literature survey (1 to 51 inclusive) strengthened the impression that spiral grain may well be the normal growth-pattern in trees.

Spiral grain in trees is of widespread importance to the users of wood products, to foresters, and to scientists. To the user of wood it is a characteristic which reduces the strength, and which is responsible for the twisting of lumber and plywood as well as being a common cause of other use problems. The forester who devotes a lifetime to growing a crop and finds that the trees are badly spiral-grained will reap less than the desired reward for his labor, so he too has a very real interest in this subject. To the scientist the phenomenon of spiral grain presents many challenges. How does spiral grain develop in a plant? Of what use is spiral grain to the plant? Can the spiralling tendency of a plant be controlled? In short, spiral grain in trees affects everybody, yet, because of the ease with which it can be overlooked, it has not been given the study which it undoubtedly deserves.

The presence of spiral grain in wood products has been known for many years. Boards and timbers with this type of grain have been removed from buildings which were built at a time when only prime logs were taken from

¹ A contribution from the Vancouver Laboratory, Forest Products Laboratories of Canada, a Division of the Forestry Branch, Department of Northern Affairs and National Resources. Accepted for publication January 30, 1957.

the forest. They performed satisfactorily for the life of the building because they were used in non-critical positions. It is emphasized that mild spiral does not detract unduly from the usefulness of wood products.

Because the most severe spiral is usually in over-mature trees, it is to be expected that, as virgin forests are logged, wood products will be less subject to severe spiral than they have been in the past. Knowledge regarding spiral grain in trees can be used to improve the usefulness of wood products derived from existing stands and to improve the quality of wood products from future forests.

MEASUREMENT OF SPIRAL

To determine the spiral orientation of the cells in mature trees a section about three inches long was sawn from a portion of the log which appeared to be free of knots. This section was first halved and then split through the pith with a straight-edged wedge as illustrated by Figure 1. The split tends to follow the grain of the wood, thus exposing any spiralling of the grain. This method gives a continuous record of the spiral habit of the tree from pith to bark and yields much more information than that obtained by examining the spiral only at the surface of the tree. To insure that the method did indicate the spiral habit of the tree it was checked just under the bark by means of the scribe, then a few years' growth was removed by means of a jointer and the new spiral determined with the scribe, and so on until the pith was reached. Both methods yielded similar results, so the efficacy of the splitting technique was confirmed. In some trees there is sufficient difference in the spiral pattern of opposing radii of the same diameter that it is necessary to average the two in order to obtain the average spiral for that cross-section of the tree.

The axis of the pith of the section was chosen as the reference line about which spirality was measured. The two major reasons for this choice were: first, the axis of the pith of the tree was considered to be more fundamental than the axis of the tree, and second, in practice, the axis of the pith can usually be determined with greater accuracy than the axis of the tree.

When spiral grain analysis was commenced, using the splitting technique, the changes of spiral from pith to bark were measured by means of a drafting machine. This method, being time-consuming and not suitable for field work, was discarded in favor of the spiral-grain protractor illustrated in Figure 2. This instrument, which was improvised from a machinist's protractor, provided an accuracy of $\pm 1/4^\circ$ which was considered to be adequate.

In the case of the leaders of seedlings three methods were used to record the presence or absence of spiral grain. In the beginning, the scribe method, which was designed to show the presence of spiral grain in lumber, was used (Koehler 22). In the case of certain species, including alder, poplar and western red cedar, it was discovered that the spiral at the pith could be determined by careful examination of the phyllotaxy—the appropriate leaves, instead of lying vertically above one another, forming a slow helix up the stem. The third method of estimating the spiral in seedlings was the injection of a suitable dye into the xylem, immediately below the cambium, by means of

FIGURE 1

FIGURE 1. Splitting Specimens.

FIGURE 2. Spiral Grain Protractor.

FIGURE 3. Representative Spiral Grain Patterns in Douglas Fir.

FIGURE 2

FIGURE 3

a small hypodermic needle with a reservoir of dye. After allowing time for the dye to travel up and down the stem the bark was peeled and the path of the dye observed.

In the case of the leaders of seedlings the spiral was usually recorded as the number of inches to complete one revolution of the stem. In other cases the spiral was recorded in degrees. The mid-diameter was recorded so that either method could be transposed to the other.

DATA

Figure 3 is a photograph of six pieces of mature Douglas fir which were prepared with the splitting technique. They illustrate the variety of spiral grain patterns which can occur in a single species.

The work to date has involved analysis of spiral grain in 594 sections of mature trees and 709 seedlings as follows:

(a) Mature Trees

- 243 cross-sections of western red alder, *Alnus rubra* Bong.
- 140 cross-sections of Douglas fir, *Pseudotsuga taxifolia* (Poir) Britton.
- 93 cross-sections of western hemlock, *Tsuga heterophylla* (Raf.) Sarg.
- 69 cross-sections of black cottonwood, *Populus trichocarpa* Torr. and Gray.
- 37 cross-sections of lodgepole pine, *Pinus contorta* Dougl.
- 7 cross-sections of western larch, *Larix occidentalis* Nutt.
- 7 cross-sections of alpine fir, *Abies lasiocarpa* (Hook.) Nutt.
- 3 cross-sections of western red cedar, *Thuja plicata* Donn.
- 2 cross-sections of willow, *Salix* sp.
- 2 cross-sections of cherry, *Prunus* sp.
- 1 cross-section of rock elm, *Ulmus Thomasi* Sarg.
- 1 cross-section of *Araucaria* sp.

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This may be considered to be a small sample, and in the overall picture it is, but it is comparable with a sample of 86,000 cross-sections in which the spiral is measured only at the surface of the tree.

In a study of this nature it is difficult to foresee the way the study will progress, and it becomes necessary to advance from less complete to more complete knowledge, improvising equipment and techniques as experimentation proceeds. For this reason all data are not of uniform accuracy, although adequate for the purpose for which they were collected. At first, sections for the study of spiral grain were obtained from logs which had been delivered to local mills. The region in which each tree grew was known but there was no detailed information on the growing site. Information regarding the position in the tree was limited, except that the specimens were obtained from the lower third of the tree, and that in some cases specimens were obtained from both the top and bottom of a log. Care was taken to choose shipments of logs from widely separated geographical regions so as to provide a range of growing conditions. In the case of Douglas fir, the species collected from the widest

geographical range, shipments were obtained from ten localities in British Columbia and Washington. These ranged from near sea level in the Vancouver Forest District to the interior plateau in the Fort George Forest District. Somewhat less detailed information regarding the spiral in Douglas fir was collected from near sea level at Big Basin State Park in the Monterey Peninsula of California and from Lake Tahoe on the California-Nevada border at an elevation of approximately 7,500 feet above sea level. Lodgepole pine specimens were taken from a shipment of fire-killed mine timbers from the foothills of Alberta.

Species from which only a few specimens were obtained were of unknown origin. By the time red alder and western hemlock were collected enough had been learned about the general patterns and techniques to justify more detail, including sampling on the growing site, collection of site and soil information, and systematic sampling of the trees at uniform heights above the ground.

Only three of the 594 specimens, i.e. 0.4 per cent, exhibited zero spiral from pith to bark: one western red cedar, one black cottonwood, and one red alder. As none of these trees had reached decadence, it is not known whether they eventually might have developed some spiral.

(b) Seedlings (mostly 1- and 2-year-olds)

- 440 Red alder, *Alnus rubra* Bong.
- 107 Black cottonwood, *Populus trichocarpa* Torr. and Gray.
- 92 Douglas fir, *Pseudotsuga taxifolia* (Poir) Britton.
- 21 Western red cedar, *Thuja plicata* Donn.
- 8 Western hemlock, *Tsuga heterophylla* (Raf.) Sarg.
- 7 Lombardy poplar, *Populus nigra* L. var. *italica* Meunch.
- 7 Sitka spruce, *Picea sitchensis* (Bong.) Carr.
- 4 Western larch, *Larix occidentalis* Nutt.
- 4 Broadleaf maple, *Acer macrophyllum* Pursh.
- 3 Grand fir, *Abies grandis* (Dougl.) Lindl.
- 3 Carolina poplar, *Populus Eugenei* Simon-Louis.
- 3 Rock elm, *Ulmus Thomasi* Sarg.
- 2 Arbutus, *Arbutus menziesii* Pursh.
- 2 Lodgepole pine, *Pinus contorta* Dougl.
- 2 Western white pine, *Pinus monticola* Dougl.
- 2 Scots pine, *Pinus sylvestris* L.
- 2 Cascara, *Rhamnus purshiana* D.C.

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Six hundred and forty-three or 81 per cent of these were recorded as having spiral in the leader. In certain species the difficulties of measuring the presence of spiral in the leader of a one- or two-year-old seedling cast some doubt upon the accuracy of individual measurements. However, there is no doubt regarding the presence of spiral in the leaders of a large percentage of all of the species examined.

In addition to the above listed original work, a survey of spiral grain literature revealed at least 86 species in which spiral grain was mentioned (1 to 51 inclusive). Champion (10) states that Braun (in papers published between 1852 and 1870) "examined 167 species, finding appreciable twist in no less than 111 of them".

If interlocked grain is included as a type of spiral grain—and no valid argument for classifying it as a different phenomenon has come to mind—then a large percentage of tropical hardwoods must be added to this list. Of 258 species listed by Kribs (25), approximately 74 per cent are classed as being subject to interlocked grain.

Spiral grain has been recorded in trees from all continents, from both north and south of the equator, and from elevations between sea level and the limits of tree growth. It has been recorded for gymnosperms and for both storied and non-storied angiosperms, i.e., from the simplest to the most complex woods. It has been recorded both in the leaders of saplings and in mature trees.

ANALYSIS OF DATA

In the following section data are analysed and presented to demonstrate the nature of the differences observed.

(I) Between Classes

Spiral grain has been recorded in woods of simple structure such as the gymnosperms (e.g., *Pinus*, *Picea*, *Abies* spp.) in woods of intermediate complexity such as the non-storied angiosperms (e.g., *Alnus*, *Betula*, *Castanea*, *Eucalyptus* spp.) and in the most complex woods, the storied angiosperms (e.g., *Cistanthera papaverifera* A. Chev., *Pentace burmanica* Kurz, and *Swietenia mahogani* Jacq.). Available evidence, i.e. that from these studies and Burger (5, 7), Champion (10), Rault and Marsh (42), suggests that all gymnosperms may follow a pattern of spiral grain analagous to that which has been demonstrated for lodgepole pine and Douglas fir, namely, a left spiral during youth passing through zero spiral to a right spiral at maturity. In the case of angiosperms there appears to be more variety, *Tilia* and *Ame-lanchier* (Champion (10)) being reported to follow the left-to-right pattern observed in gymnosperms, and *Pyrus* (Braun (6)) and *Alnus* tending to follow the opposite pattern of right during youth progressing to left at maturity, while still others tend to continue the spiral direction of youth to maturity (*Populus trichocarpa* Torr. and Gray).

(II) Between Species

Figure 4 was prepared to demonstrate the nature of the differences between species. Lodgepole pine and Douglas fir commence life with a left spiral, pass through zero spiral during mid-life, and develop a right spiral at old age. These species exhibit a great difference between the ages at which zero spiral is developed. Red alder follows a pattern which is the reverse of the softwoods, trending from right spiral at youth to left at maturity. Black cottonwood follows still another pattern, tending to increase its initial spiral rather than to change from right to left or vice versa. It would appear that each species

FIGURE 4. Differences Between Species.

might have its own particular pattern of spiral behavior and Champion (10), in his very comprehensive literature review, gives a number of references which confirm this view.

(III) Between Localities, Within a Species

The Douglas fir data will be used to demonstrate the nature of the differences to be anticipated between different localities of growth. Each curve of Figure 5 represents the average spiral from pith to bark for a particular shipment. With one exception all shipments follow the same general pattern of left spiral at youth proceeding through zero to right spiral at old age. However, each has done so to a different degree, Shipment 4 having passed through zero at 104 years of age and having developed an average spiral of 4° right at 250 years whereas Shipment 8 passed through zero at 300 years of age and developed an average spiral of only 0.8° at 357 years of age. The single exception, Shipment 1, contained a large percentage of interlocked grain which may have masked the species trend from left to right. Another difference which was noted between the Douglas fir shipments, and which is illustrated by Shipments 3 and 4 of Figure 6, was that the trees from certain regions (shipments) were prone to interlocked grain whereas other shipments were free from this type of grain.

FIGURE 5. Illustrating Differences Between Localities (Douglas Fir).

Differences corresponding to those presented in Figure 5 were noted for the samples of red alder from two different localities. Such differences were anticipated on the basis of Champion's references to "spiral grain areas" and "relatively spiral-free areas" with Chir pine in India (10, 11, 12).

(IV) Between Trees, Within a Species, Within a Locality

For Douglas fir the differences to be expected between trees within a species and locality are shown photographically in Figure 3 and graphically by Figure 6. A majority of the specimens (64 per cent) had a left spiral during youth which passed through zero to a right spiral at old age (specimens 1 to 4 of Figure 3). Nineteen per cent increased the left spiral of youth to old age (or failed to reduce it substantially, specimen 6 of Figure 3). The remaining 17 per cent exhibited most of the other possible combinations. A pattern of interlocked-grain was super-imposed upon the spiral-grain pattern of many of the trees (specimens 4 and 5 of Figure 3) but was absent from others. The first difference, then, was in the general pattern of the spiral: left, left changing to right, or either of those with a superimposed pattern of interlocked-grain. Another difference was in the intensities of spiral developed. Certain specimens developed maximum spirals as great as 16° left, others 19° right while certain specimens had as little as 2° left and $\frac{1}{2}^{\circ}$ right.

The differences between red alder trees are observable in Figure 7 and are comparable in magnitude although not in pattern, with those noted for Douglas fir.

FIGURE 6. Illustrating Differences Between Localities (Shipments), Between Trees, and Radially Within a Tree.

(V) Within a Tree

(a) Radially

With three exceptions out of 594 cross-sections from 12 species the spiral changed continuously from pith to bark. Characteristic patterns include left spiral near the pith changing to right at maturity, continuously increasing left spiral, right spiral near the pith changing to left spiral at maturity, continuously increasing right spiral, or variations of these patterns. In addition each of the above patterns may be modified by a superimposed pattern of

FIGURE 7. Illustrating Differences Between Trees and Radially Within a Tree at Breast Height (Red Alder).

interlocked-grain. With the exception of the three straight-grained specimens, no two cross-sections were observed with identical spiral patterns from pith to bark. This point is demonstrated by the specimens plotted in Figures 6 and 7. Various literature references confirm the differences observed radially within a tree. Champion (10) says of Braun's work: "One of the most important of Braun's contributions was the firm establishment of the fact that a change in the direction of the spiral with age is quite usual: *Pinus*, *Picea*, *Abies*, *Tilia*, and *Amelanchier* were all found to be L in youth changing to R later in life—no satisfactory case of the opposite possibility being found". Burger (6) states: "The examination of 3,843 trunks of Pear and 3,446 trunks of Apple on the Swiss plateau between Lake Constance and Lake Bienné has revealed that twist to the right of fibres of the Pear tree increases with age and girth, even though, in the case of the closely related species, the Apple, the fibres turn more from right to left as the tree grows older. We will have the opportunity later of showing a similar contradiction in the behavior of different groups of the Pine species".

Another difference worthy of note is that the spiral pattern from pith to bark is not identical for different radii of the same cross-section. Misra (31) has recorded such differences for Chir pine and Paul (35) for ponderosa pine.

(b) Vertically

The change of spiral angle with height above the ground, based upon 25 alder trees, is summarized in Figure 8. The solid line, representing the average for all ages from the pith, shows a continuous change from left spiral at 4½ feet above ground to right spiral at 40 feet above ground. The dotted

lines, representing the change of spiral with height for each tenth year's growth from the pith, follow similar trends. Another sample of alder from a different site, with 14 trees, failed to follow the above pattern, height above the ground appearing to have little influence upon the spiral. A sample of nine western hemlock trees likewise indicated no correlation between height and spiral. This does not mean that spiral was uniform throughout the height of each tree, but that considerable differences existed between the patterns of different trees which, in this sample, tended to cancel one another.

The Director of Forests, Queensland (40), referring to plantation-grown *Araucaria cunninghamii*, reports that "spirality increases with increasing height". Paul (35) shows the same trend for an 80-year-old stand of ponderosa pine.

(c) *Seedlings*

(1) Douglas fir

Table 1 is a summary of the information gathered from two-year-old Douglas fir seedlings which were grown in nursery beds at the University

FIGURE 8. Illustrating the Relationship Between Spiral Angle and Height Above the Ground (Red Alder).

of British Columbia. The wind-pollinated seeds were from a wide range of climate and site, from as far south as Mendoceno, California, and as far north as Kamloops, British Columbia.

It is of interest that the majority of seedlings appear to commence life with a left spiral but that a significant percentage commence life with a right spiral. This is similar to the pattern observed with the splitting technique for

FIGURE 9. Illustrating Differences Between Specimens and Radially Within Specimens of 2-year-old Seedlings (Red Alder).

TABLE 1
SPIRAL IN 2-YEAR-OLD DOUGLAS FIR SEEDLINGS

Seed Source	Height (inches)		Spirals					
			2-year-old wood			1-year-old wood		
	Plant	Leader	Left	Zero	Right	Left	Zero	Right
Louella, Wash.	21	14	3	2	0	5	0	0
Surrey, B.C.	20	14	4	1	0	5	0	0
Foster, Ore.	20	14	3	2	0	3	2	0
Ashford, Wash.	19	14	3	0	2	5	0	0
Sequim, Wash.	19	13	4	1	0	3	2	0
Mendoceno, Cal.	19	13	3	2	0	4	1	0
Enumclaw, Wash.	17	11	3	2	0	4	0	1
Veronia, Ore.	16	11	3	0	2	4	0	1
Nanaimo, B.C.	16	11	3	1	1	2	3	0
San Juan, Wash.	15	10	2	1	2	3	2	0
Salmon Arm, B.C.	13	9	4	0	1	1	2	2
Heffley Lake, B.C.	10	8	2	2	1	3	0	2
Nelson, B.C.	8	5	4	0	1	2	2	1
Colorado, Idaho	7	4	3	1	1	2	2	1
Kamloops, B.C.	6	3	3	1	1	1	1	3
Prior Mt., Montana	5	2	1	2	2	1	3	1
			48	18	14	48	20	12
			60%	22%	18%	60%	25%	15%

mature trees. Whether or not the individuals which have been classed as having zero spiral actually do have zero spiral or have been so classed because of the difficulties of measuring the spiral is not certain.

(2) Red Alder

The simple phyllotaxy of alder, every third leaf arising from the same point of the triangular pith, provides an accurate and convenient method of measuring the spiralling of the cells associated with the pith and primary xylem. The spiral was measured in 440 alder seedlings using the three different methods described under "Measurement of Spiral". For the purpose of this discussion the pertinent data were obtained from a sample of 50 two-year-old seedlings which were growing in an abandoned forest nursery adjacent to the mature alder of Figure 7. It was because of the probable relationship between these seedlings and the trees of Figure 7 that they were studied in detail. Information regarding the spiral in these seedlings was taken in sufficient detail to estimate the spiral in the primary xylem, in the early secondary xylem, in the late secondary xylem, at the end of the first season's growth and at the end of the second season's growth. A few representative specimens from these data have been plotted in Figure 9. The mean is indicated by the dots. Comparison of Figure 9 with Figure 7 indicates that the pattern is

TABLE 2

Species and Stump Number	SPIRAL TENDENCIES OF SPROUTS FROM THE SAME STUMP		
	Spiral		
	(inches to complete one revolution of stem)		
	Left	Zero	Right
Red Alder			
1	28	R, O, L	48
	16		100
	40		50
	40		30
	36		24
			32
2	28		45
	40		24
	100		32
	28		35
3	72		64
	64		40
	64		
	48		
4		R, O, L	40
		R, O, L	60
		O	
5	44		26
	80		20
	40		24
	40		64
Black Cottonwood			
1	160		160
	150		
2		O	180
		O	150
3	160		180
	250		150
4		O	160
			120
			120
			120
5	175	O	140
			100
			110

rather comparable with that recorded for the mature trees; no two trees have identical spiral patterns, some have right spirals, others left, some change from right to left, and vice versa. This changeover of spiral from right to left, or vice versa, has been recorded both vertically and radially in a single year's growth of a plant.

(3) Black Cottonwood

This is another species whose phyllotaxy lends itself to measurement of the spiral at the pith and primary xylem, every fifth leaf arising from the same point of the pentagonal pith. Although this species has not been studied in as great detail as red alder, it is evident that the seedlings may follow all of the patterns observed for the latter species. In general, the severity of spiral is much less for cottonwood than for alder. Literature references regarding the presence of spiral in the leaders of seedlings appear to be contradictory. Champion (10) quotes Braun as saying that: "He could detect the twist even in one year old shoots (pine)" but he himself says of Chir pine: "Twisted fibre is practically never developed during the first season of growth". Kadambi and Debral (19), in reporting upon a continuation of Champion's work with Chir, state: "Twist can be recognized even in the cotyledonary leaves of germinating seeds thus enabling the weeding out of the undesirable seedlings from field sowings or nursery beds".

(d) Leaders vs Limbs

Records kept for red alder trees, including mature trees, saplings, and seedlings, have demonstrated that there is no consistency between the spiral in the leader and that in the limbs, most trees having an approximately equal percentage of right and left spiralling branches regardless of the spiral in the leader. This phenomenon is not peculiar to hardwoods alone as in western red cedar a similar lack of consistency was noted between the spiral in the leader and that in the limbs. The difference, however, was not as great as with alder, a majority of the limbs exhibiting the same direction of spiral as the leader, although the intensity of spiral varied greatly from limb to limb.

(e) Stump Sprouts

Table 2 indicates that either left, right, or zero spirals may develop in sprouts from the same stump. It also shows that the intensity of the spiral differs from sprout to sprout. The spiral recorded is that of the pith. Where R, O, L occurs in the zero column it indicates that the pith had a right spiral in the pith of the lower stem which passed through zero to a left spiral higher up the stem. The rather large differences between the spirals of the two species are worthy of note.

Champion (10), comparing the spiral of single stump sprouts of Chir pine with their original stocks, says: "These figures show that all variations occur though a tendency of the coppice shoot to follow the lead of the original axis is discernible . . .".

SUMMARY OF OBSERVATIONS

- (1) Spiral grain appears to be independent of the complexity of the wood structure, having been recorded in gymnosperms and in both non-storied and storied angiosperms.
- (2) Each species appears to have its own more-or-less characteristic pattern of spiral grain, certain species trending from left in youth to right at maturity, others having the reverse tendency, and still others tending to increase the initial spiral of youth to maturity. Any of these may have superimposed interlocked grain. Certain individuals of a species vary widely from the average of the species.
- (3) Trees of the same species, grown in widely separated regions, appear to develop significantly different severities of spiral grain.
- (4) One of the most striking observations was the extreme variability in the spiral tendency of trees of the same species growing in close proximity to one another.
- (5) Within a single tree, spiral varies:
 - (a) radially from pith to bark (i.e., with age and with radius);
 - (b) along different radii of the same cross-section in some specimens;
 - (c) with height above the ground;
 - (d) from limb to limb, or from stump sprout to stump sprout, both in direction of spiral and intensity of spiral;
 - (e) within a single year's growth of a seedling to the extent of reversing its spiral from left to right, or vice versa, this reversal of spiral in the leader during a single season's growth has been recorded both vertically in the stem and radially from pith to bark.
- (6) It appears to be characteristic of a tree to develop spiral grain of varying severity, commencing with the primary xylem and changing more or less continuously throughout its life. A so-called "straight-grained" tree is probably just passing through zero spiral from left to right or vice versa. Spiral grain was present in 99.6 per cent of the 594 mature trees inspected.

IS SPIRAL GRAIN THE NORMAL GROWTH PATTERN?

No claim is made that this has been proved, but all of the data reported support the theory that spiral grain is the normal pattern of growth in trees. This thought was expressed by Champion (10), but rejected in the following words: "The occurrence of spiral form is so commonplace (Cook (39)) as hardly to require mention; in fact one is almost tempted to treat it as the normal condition and look for reasons to account for growth in straight lines". Preston (38) says: "One wonders how many saplings really have straight grain. A certain degree of spiral grain may well be more common than supposed, although only in special cases, or under special conditions, does the spiral become so excessive as to be easily observable".

The importance of this change of emphasis, from abnormality to normality, lies in the change of attitude which it engenders. The user of wood must try to recognize and make the best use of excessively spiraled specimens, the forester must strive to minimize it in the forests of the future, and the scientist must fathom its secrets.

REFERENCES

1. BANKS, C. H. Spiral grain and its effect on the strength of South African grown pines. J. S. Afr. For. Ass. No. 23: 1-6. 1953.
2. BHAT, R. V., and M. M. SINGH. Wrapping papers from *Chir* (*Pinus longifolia* Roxb.) of twisted grain. Indian For. 81(12): 765-73. 1955.
3. BOAS, I. H. Cross, diagonal and spiral grain in timber. C.S.I.R.O., For. Prod. Div. Aust. Trade Circ. No. 13. 1933.
4. BRADLEY, C. B. The twist of wood-fiber in the tamarac pine. Madrono 1: 63-6. 1918.
5. BURGER, H. Der Drehwuchs bei den Holzarten. I. Drehwuchs bei Fichte und Tanne. Schweiz. Anst. forstl. Versuchsw. 22(1): 142-64. 1941.
6. BURGER, H. Der Drehwuchs bei Birn- und Apfelbäumen. Schweiz. Z. Forstw. 97(3): 119-25. 1946.
7. BURGER, H. Das "Arbeiten" imprägnierter Leitungsmasten. Schweiz. Anst. forstl. Versuchsw. 29(2): 177-88. 1953.
8. CAHN, A. R. Twisted trees. Science 73(1899): 561. 1931.
9. CASTLE, E. S. Spiral growth and reversal of spiralling in *Phycomyces*, and their bearing on primary wall structure. Amer. J. Bot. 29, 664. 1942.
10. CHAMPION, H. G. Contributions towards a knowledge of twisted fibre in trees. Indian For. Rec. 11, Pt. II: 11-80. 1925.
11. CHAMPION, H. G. An interim report on the progress of investigations into the origin of twisted fibre in *Pinus longifolia* Roxb. Indian For. 53(1): 18-22. 1927.
12. CHAMPION, H. G. Second interim report on the progress of investigations into the origin of twisted fibre in *Pinus longifolia* Roxb. Indian For. 56(12): 511-20. 1930.
13. CLARKE, C. B. On right-hand and left-hand contortion. J. Linn. Soc. (Bot.) 18(112): 468-73. 1881.
14. COPISAROW, M. The problem of twisted trees. Science 77(2007): 581-3. 1933.
15. GORRIE, R. M. Twisted fibre in *Pinus excelsa*. Indian For. 64(3): 185-8. 1938.
16. GRIFFITH, A. L. Twisted fibre in conifers. Indian For. 72(11): 512-3. 1946.
17. JACOBS, M. R. The occurrence and importance of spiral grain in *Pinus radiata* in the federal capital territory. Leaf. For. Bur. Aust. No. 50. 1935.
18. JACOT, A. P. Tree twist. Science 74(1927): 567. 1931.
19. KADAMBI, K., and S. N. DABRAL. On Twist in *Chir* (*Pinus longifolia* Roxb.). Indian For. 81(1): 58-64. 1955.
20. KNORR, F. What causes twisted trees. J. Hered. 23(2): 49-52. 1932.
21. KOEHLER, A. The "Grain" of wood with special references to the direction of the fibres. U.S. For. Prod. Lab., Madison, Rep. No. R262. 1929.
22. KOEHLER, A. Guide to determining slope of grain in lumber and veneer. U.S. For. Prod. Lab., Madison, Rep. No. 1585. 1943.
23. KOEHLER, A. More about twisted grain in trees. Science, 73(1896): 477. 1931.
24. KOHL, E. J. An explanation of the cause of spiral grain in trees. Science 78(2012): 58-9. 1933.
25. KRIBS, D. A. Commercial foreign woods on the American market, a manual to their structure, identification, uses and distribution. Tropical Wood Laboratory, State College, Pa. 1950.
26. KROGH, P. M. D. The twisting of wooden telephone poles in service in South Africa. S. Afr. For. Prod. Inst., Pretoria West, Pap. presented at Comm. For. Conf., Canada. 1952.
27. LIMAYE, V. D. Interlocking of grain in Indian timbers. Indian For. 80(1): 6-9. 1954.
28. MCCARTHY, E. F., and R. J. Hoyle. Knot zones and spiral in Adirondack red spruce. J. For. 16(7): 777-91. 1918.

29. McKINNEY, H. H., and W. J. SANDO. Twisted wheat and twisted trees. *J. Hered.* 25(7): 261-3. 1934.
30. MILLER, E. C. L. Spiraling in trees. *Science* 80(2063): 35. 1934.
31. MISRA, P. Correlation between eccentricity and spiral grain in the wood of *Pinus longifolia*. *Forestry* 17: 67-80. 1943.
32. MISRA, P. Observations on spiral grain in the wood of *Pinus longifolia*, Roxb. *Forestry* 13(2): 118-33. 1939.
33. OSTLIND, B. Slope of grain chart aids inspectors. *Timberman* 44(5): 26. 1943.
34. PAUL, B. H. Spiral grain tends to cause warping in sand pine lumber. *Forest Worker* 8(5): 7-8. 1932.
35. PAUL, B. H. Changes in spiral grain direction in Ponderosa pine. No. 2058, U.S.D.A. For. Prod. Lab., Madison, Wisc. 1956.
36. PEMBERTON, C. C. A revolving growth movement in conifers. *For. Cl. Quart.* 8(4): 5-9. 1929.
37. PRESTON, R. D. The molecular architecture of plant cell walls. Chapman and Hall, London. 1952.
38. PRESTON, R. D. Spiral structure and spiral growth, the development of spiral grain in conifers. *Forestry* 23(1): 48-55. 1949.
39. PRIESTLY, J. H. Observations on spiral grain in timber. *Amer. J. Bot.* 32(5): 277-84. 1945.
40. QUEENSLAND. Report of the director of forests, 1954-55, p. 24. Qd., For. Dept. Brisbane. 1955.
41. RAO, H. S. The phenomenon of twisted trees. *Indian For.* 80(3): 165-70. 1954.
42. RAULT, J. P., and E. K. MARSH. The incidence and silvicultural implications of spiral grain in *Pinus longifolia*, Roxb. in South Africa and its effect on converted timber. *S. Afr. For. Prod. Inst., Pretoria West, Pap.* presented at Comm. For. Conf., Canada. 1952.
43. SEIFRIZ, W. More about the spiral habit. *Science* 78(2025): 361-3. 1933. Abstract in *Indian For.* 60(6): 443. 1934.
44. SMALL, J. K. The crux of twisted and contorted tree-trunks. *J. N. Y. Bot. Gdn.* 33(393): 189-95. 1932.
45. TIEMANN, H. D. What is "spiral grain"? *Sch. Lumberm.* 163: 55-7. Nov. 15, 1941.
46. TOUMEY, J. W., and C. F. KORSTIAN. Seeding and planting in the practice of forestry. 2nd ed. p. 156. Wiley, New York. 1931.
47. TURNBULL, J. M. A preliminary investigation into the causes of torsion in pine stems. *J. S. Afr. For. Ass.* No. 8: 112-7. 1942.
48. VAN OYE, P. Sur la torsion des troncs d'arbres. *Bull. Soc. Bot. France* 73 (3-4): 270-8. 1926.
49. WENTWORTH, C. K. Twist in the grain of coniferous trees. *Science* 73(1885): 192. 1931.
50. WILSON, T. R. C. The effect of spiral grain on the strength of wood. *J. For.* 19(7): 740-7. 1921.
51. YEAGER, W. C. Regarding twist in conifers. *Science* 73(1893): 392-3. 1931.