The Influence of Tracheid Length and Density in Sitka Spruce[1]

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Introduction

THE influence of tracheid length upon wood properties has been demonstrated by several research workers. Watson *et al.* (1952), quoted by Elliott (1960), have shown a definite correlation between the tensile strength of paper and tracheid length. Strongly associated properties are bursting strength and folding endurance. Dadswell (1957), quoted by Elliott (1960), considers that the average tracheid length is one of the most important structural features related to wood quality and one of the easiest to measure.

Wood density is the simplest and most useful index of the suitability of wood for many important uses and is very easily and quickly measured. There is a high degree of correlation between density and the mechanical strength of all woods (Mitchell, 1960). Density is therefore a primary factor in the segregation of structural grade timbers that command premium prices, and also in the selection of material for transmission poles and other uses where strength is of major importance.

The northwest American tree species Sitka spruce *(Picea sitchensis* (Bong.) Carr). is the most important exotic conifer in Irish forestry. In 1972/73 it comprised 65.7% of the various species established in State plantations (Report of the Minister for Lands, 1973). Sitka spruce is generally planted pure, in upland regions where it's main requirement, for adequate moisture, can be most easily met. In general, the timber is of uniform light colour without a distinct heartwood. It normally has an average nominal specific gravity of approximately 0.33 and a growth rate of about 3 to 8 annual growth rings per inch (Wood & Bryan, 1960).

A considerable amount is known about the general behaviour of Sitka spruce as a plantation species but, until now, most research has been concerned with improving growth rate with consequent

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increases in yield through such practices as fertilisation. Little is known of the variation patterns within the tree and of it's response to various silvicultural treatmenıs at a basic wood structure level.

It seems therefore desirable to assess the effects, if any, of silvicultural treatment on two wood properties namely: tracheid length and density.

Factors contributing to Variation in Wood

Wood cells originate as a result of divisions of the cambium cells. However, variation in cambial activity commonly occurs, not only between trees, but also during the lifetime of an individual tree.

The result of varying cambial activity is that the average length of a population of cambial initials does not remain constant. As the cambial zone moves outwards with increasing diameter of the stem, the average length of cambial initials usually increases over the first few centimetres and then becomes less predictable. This variation in the length of cambial initials is the primary cause of variations in wood quality.

The wood formed within and immediately below the active crown is known as juvenile wood. It is characterised anatomically by a progressive increase in the dimensions of the component cells and it also exhibits corresponding changes in form, structure and disposition of the cells of successive growth rings (Rendle, 1960). Research has shown that for most temperate conifers the wood in the first ten to fifteen rings from the pith is characterised by:

(1) Rapidly increasing tracheid length of the order of 300% (Dinwoodie, 1963).
(2) Whole-ring density values which fall from a maximum value and thereafter rise slowly (Brazier, 1967).
(3) Cell wall thickness which decreases in the earlywood and increases in the latewood of the annual ring (Brazier, 1967).

The major changes in wood formation and quality are therefore in the lower stem region beneath the living crown.

Wood formation is affected by a variety of environmental conditions. Variable weather conditions produce variation in wood quality because of fluctuations in the growing conditions. Liese & Dadswell (1959), quoted by Bannan & Bindra (1970), after examination of many trees in both northern and southern hemispheres, reported that rings were widest and the longitudinally orientated cells shortest on the sunny side of the stem. It was concluded that warmth stimulated cell division and favoured reduced cell length. Furthermore, Derby & Gates (1966) have shown that cambial temperatures were highest on the south and east sides of aspens in Colorado, U.S.A. It is to be expected therefore, that a mosaic pattern of cambial heating would prevail in the tree, with changes from hour to hour depending on the angle of insolation and branch arrangement.

Bannan & Bindra (1970) noted inequalities in the amount of radial growth around the stem. Working with three species; White spruce (*Picea glauca* (Moench Voss), Lodgepole pine (*Pinus contorta* var. *latifolia Engelm.*), and Eastern white pine (*Pinus strobus* L.) they showed that growth rings tended to be wider on the east than on the west side of the stem. Because this pattern of unequal growth is of common occurance in trees of the northern hemisphere, where the prevailing wind is from the west, it was concluded that the two phenomena were related.

Within the forest, control of the finished product can be exercised by manipulation of an array of silvicultural tools, including genetics, fertilisation and spacing. This study is concerned with the last of these three.

Systematic Variation of Wood Properties within the Stem

1. Tracheid Length

The foundation of the study of tracheid length variation was laid down by Sanio in 1872. He presented the results of his studies on Scots pine (*Pinus sylvestris. L.*) in a set of five conclusions, which are now generally referred to as 'Sanio's Laws' (Baily & Shepard, 1915). Briefly they are:

(i) In a radial direction from the pith, tracheid length increases until a maximum is reached. From this point outwards the length remains constant.

(ii) Longitudinally from the stump upwards tracheid length increases to a maximum, thereafter decreasing with further height increase.

The constant tracheid length reported by Sanio has not been entirely corroborated. Bailey & Shepard (1915), working on basal sections of four conifers, found that the initial increase was followed by wide fluctuations. Furthermore, Gerry (1916), reported that in Douglas fir (*Pseudotsuga menziesii* (Mirab. Franc.)) the increase in length up to 20 years was marked, but thereafter became erratic.

(a) Variation within the Annual Ring

There is general agreement in the literature that in all species having distinct growth rings, there is radial variation in the length of tracheids within any given annual ring.

Dinwoodie (1961), has shown that in Sitka spruce the last formed tracheids in the ring are 5% to 10% longer than those at the beginning of the ring, and 17% to 30% longer than those of minimum length in the centre of the ring. This does not apply to the three rings nearest the pith.

(b) Variation in Tracheid Length outwards from the Pith at any one level

All investigations into this aspect of tracheid length have recorded the same general trend. Cell length in the ring nearest the pith is very short (0.5 to 1.5 millimetres on average in conifers), but increases rapidly outwards in the first few rings. After this, the rate of increase declines until a maximum tracheid length is reached. Maximum tracheid length is generally 3 to 5 times greater than the initial length (Dinwoodie, 1961).

Considerable disparity appears, firstly as to whether this length increase outwards is associated with increasing ring number or with linear distance from the pith as outlined by Anderson (1951). Secondly, the controversy arises as to whether tracheid length, after increasing initially, remains constant or fluctuates.

(c) Variation in Tracheid Length with increasing Height in the Tree

This relationship may be studied from two different aspects. Either a single ring may be followed upwards in the growth sheath or, a growth ring at a constant number of rings from the pith may be traced upwards.

It is generally accepted that within the growth ring, tracheid length increases upwards for a certain distance before decreasing progressively to the top of the tree. The average length of the tracheids at the top of each ring is generally less than that of the tracheids at ground level (Dinwoodie, 1961). The position of maximum tracheid length in each growth ring, therefore, will be located at progressively higher levels as successive growth rings are formed.

There is a sparsity of data regarding the variation in tracheid length upwards in growth rings at a fixed number of growth rings from the pith. With the exception of the first formed ring, tracheid length has been found to increase with increasing height up to some point in the stem, after which, length remained constant or declined (Chalk, 1930; Elliott, 1960; Dinwoodie, 1961). In the first formed growth ring tracheid length remained constant or varied extremely little up the stem (Bisset & Dadswell, 1949).

(d) The Effect of Growth Rate on Tracheid Length

Attempts to correlate the increase in tracheid length with the age of the tree, width of growth ring and linear distance from the pith have been made by several researchers. Trendelenburg (1939) is quoted by Ahmed (1970) as having established that in spruce, wood with broad annual rings has shorter tracheids than wood with narrow annual rings. These findings were confirmed by Bisset *et al.* (1951). Early work (Chalk, 1930) indicated that there was an inverse relationship between tracheid length and ring width, recording a correlation coefficient of 0.742 ± 0.005 for Sitka spruce. Elliott (1960) investigating a 41 year old Sitka spruce stem concluded that age has a significent correlation with tracheid length, while ring width showed a negative correlation with tracheid length.

2. Density

Density is not a simple characteristic of wood, it is complex of the effect of several growth and physiological variables compounded into one fairly easily measured wood characteristic. In the anatomical sense, density is a function of the ratio of cell wall volume to cell void volume and is consequently affected by cell wall structure, average cell dimensions, lumen dimensions, amount of resin and extractives and a volume of non-fibrous elements such as rays (Elliott, 1970).

(a) Variation in Density with increasing Height in the Tree

It is long known that, for many conifers, density decreases with increasing height in the stem. In certain conifers, notable the spruces, density does not markedly decrease with height, but rather does not vary significantly or may even increase with increasing height (Farr 1973).

(b) Variation in Density outward from the Pith at any one Level.

Density also varies with the distance outward from the pith at any one height level. For young and semi-mature trees density is almost always found to increase from the pith outwards.

Although the general pattern of density variation has been established, it is impossible to say whether the trend is related to position in the tree or to age. The two factors appear to be completely confounded (Spurr & Hsuing, 1954).

(c) Earlywood, Latewood and Wood Density

Earlywood and latewood density values are not constant within a species or even within a single tree. They vary from juvenile to adult wood and also with conditions of growth. The nature of the transition from earlywood to latewood in each year's growth can also have a marked effect on average wood density (Harris, 1967).

In many conifers, the basic density of the latewood zone is more than twice that of earlywood (Paul, 1939; Fry & Chalk, 1957), thus any increase in the proportion of latewood inevitably leads to an increase in whole-ring basic density.

(d) Silvicultural Considerations in relation to Wood Density.

Paul (1946), has emphasised that wood density values can be raised if the proportion of latewood laid down is increased. Thinning, pruning and spacing control might be used to achieve this end. Thinning may have various effects. In Loblolly pine (*Pinus taeda*), release has, under various conditions, been shown to increase and sometimes decrease average density, or to have no discernable effects (Spurr & Hsuing, 1954). In addition spacings of 4×4 feet, 6×6 feet and 8×8 feet had only minor effects on average wood density (Jayne, 1958). Up to the stage of canopy closure the effect of initial spacing on basic density is not very clear. Evidence supporting an increase in value with close initial spacing is offset by evidence indicating that, within the limits of normal silvicultural practice, initial spacing has little significant effect on basic density values (Elliott, 1970).

MATERIALS AND METHODS

Materials

1. The wood used

Wood samples for all of the preliminary experiments were obtained from a 37 years old stand of Sitka spruce in Knockrath Woodlands, Laragh, Co. Wicklow.

The wood samples examined in the major experiments were taken from Sitka spruce stands at Drumhierney Plantations, Leitrim, Co. Leitrim. The stands from which samples were taken were established in 1954 at spacings of 2.4×2.4 metres (8×8 feet), 3.6×3.6 metres (12×12 feet), and 4.57×4.57 metres (15×15 feet), and have not been thinned since establishment (Dillon, 1970).

Sampling in most cases was by means of a 5 millimetres diameter increment borer. However, at Knockrath Woodlands a single stem was felled and discs approximately 2 centimetres in width were cut.

2 Laboratory Materials

The digestion solution used consisted of a 50:50 mixture of glacial acetic acid (CH_3COOH) and '100 volumes' hydrogen peroxide (H_2O_2).

The agar used was 'Oxide' Ionagar.

Methods

1. Field Operations

Non-destructive sampling was used, with one exception, throughout the investigation. It was therefore necessary to take most samples by means of an increment borer. Due to the general unavailability of large diameter (10 to 12 millimetres diameter) borers it was decided to investigate the possibility of using the method of sampling developed by Polge (1967). In this a Pressler 'Swedish-type' 5 millimetres diameter increment borer is driven into the tree at an angle of 30° to the stem.

2. Laboratory Operations

In the case of disc samples, single whole growth rings selected for maceration or for density determination, were extracted from the disc by means of a chisel. A scapel was used in the case of cores. In both cases rings were rendered more distinguishable with an aqueous solution of safranin (Kase, 1935; Hornibrook, 1936).

In the sampling of tracheids for transferance onto microscope slides a standard procedure, involving successive dilutions was established to ensure as far as possible that random sampling was being employed.

At first a sample size of 45 tracheids was adopted for assessing mean tracheid length. This was later increased to 50, with reference to Harris (1966) and Burley (1969).

Each slide in preparation for the application of the tracheid smear, was first covered with 1 or 2 millilitres of 2% Ionagar which was then allowed to dry out leaving a thin film on the slide. The tracheids were found to be secured to the slide on drying.

Tracheid length was measured by projecting an image of the slide mounted tracheids on a screen by means of a projection microscope. The magnification used was 100X and tracheid lengths on the screen were measured by means of an opisometer. Density was assessed on whole rings in the case of disc samples and on groups of whole rings in the case of core samples. In approaching wood density measurement from an ecological standpoint, density based on green volume and oven dry weight is preferable. It is an easily replicable value and its use avoids the complications arising from wood shrinkage while drying (Spurr & Hsuing, 1954).

Details of the Experiments

1. The Angle of Sampling with the Borer

Polge (1967), has suggested that increment cores taken at an angle of 30 degrees to the tree can be used when taking samples for tracheid length measurements. However, sampling at any angle with a borer must necessarily cut many tracheids. These cut tracheids make it difficult to distinguish and measure uncut tracheids. Hence it was considered desirable to examine this aspect of core sampling before proceeding to use this method routinely.

The Pressler borer is most easily driven at 90 degrees to the tree. It was therefore decided to assess and compare the number of full-length tracheids present at 4 different angles; 90, 45, 40 and 35 degrees using a ratchet handle to drive the borer.

2. A Comparison of Tracheid Length when using Disc and Core Samples

There are numerous suggestions in the literature, notably Hart & Hafley, (1967) that core sampling introduces a bias in favour of shorter tracheids.

The measurement of only the uncut tracheids from macerated cores could result in both the mean and variance of the tracheid length population being underestimated.

It was therefore decided that a disc, of approximately 2 centimetres width, be compared to a Pressler 5 millimetres diameter increment core taken from the centre of the same internode, for assessing mean tracheid length.

At the approximate midpoint of the nearest internode to 10% total tree height an increment core was taken at 35 degrees on the east side. The tree was then felled and at the same point a disc of approximately 2 centimetres width was taken and marked on the east side.

The 5th and 10th rings from the bark were selected in both cases.

3. Distribution of Tracheid Length and Density in a Single Stem of Sitka spruce

A single stem of Sitka spruce was felled in Knockrath Woodlands. Total height was assessed in metres and disc samples of approximately 2 centimetres width were taken at the approximate midpoint of the nearest internode to a series of percentage heights. These were 10, 20, 30, 40, 50, 60, 70 and 80% height. As compression wood was suspected of being present on the north radius of the disc growth rings were selected from the east side. The single selected growth rings were counted from the pith and were intended to represent a class of growth rings with an interval of 5 growth rings. In this way the rings selected were the 3rd growth ring from the pith representing the class 0–5, the 8th representing the class 5–10 and so on, for all heights sampled. The samples were macerated and slide mounted. Mean tracheid length was assessed in millimetres based on a sample size of 45 tracheids.

For the assessment of density whole growth rings were selected from both east and west co-ordinates so that a comparison could be drawn between the different values. The growth rings selected were the 4th, 7th, 12th, 17th, from the pith at the 10% height level. The 7th growth ring from the pith was selected for each discrete percentage height level from 10 to 80% total height. Green volume was assessed in cubic metres and oven dry weight in Kilogrammes. Density was expressed in Kilogrammes/cubic metre.

4. The Influence of Spacing on Tracheid Length and Density.

Information was not available with regard to the mean and standard error of tracheid length in Sitka Spruce in Drumhierney Plantations. Consequently, it was not known how many trees should be sampled. In the absence of a pilot survey it was decided to adopt a sample size of 15 trees, with reference to Henderson & Petty (1972) and Joyce (1975).

To ensure, as far as possible, that random sampling was being employed in the selection of trees for sampling, maps of the area with all trees numbered in the rows were consulted (For. Dept. U.C.D., 1970). 15 random numbers were extracted from a table of random numbers for each spacing and the trees located on the map and subsequently in the field in this manner. It was decided to use 10% height on the east side of all selected trees, as the sampling point.

Total tree height (in metres) was assessed using a blume leiss hypsometer. 10% height was located using a metric measuring tape. A core was then taken at 35 degrees to the tree. A total of 45 cores were taken, over the 3 spacings, in this manner. The average time taken to locate each sample tree and take a core was 15 minutes.

In the laboratory growth rings were counted from the bark in order to be able to compare rings of similar age. In this way the 5th and 10th were selected and macerated and density assessed for the interval of growth rings i.e. the 6th to the 9th inclusive. Mean tracheid length was assessed in millimetres based on a sample size of 50 tracheids.

Results

1. Angle of Sampling

It was found that, in Sitka spruce, it was not possible to take samples at an angle of 30 degrees to the vertical axis of the tree. Unbroken, clean cores could, however be successfully taken at angles of 35, 40, 45 and 90 degrees provided that quarter turns of the borer were used to obtain a clean initial cut particularly at the lower angles.

A core sample which is taken at 90 degrees to the tree has a circular tangential face. The taking of a core at an angle of less than 90 degrees produces an elliptical tangential face. Since the effect of taking a core at an acute angle results in an increase in the long diameter of the ellipse and since tracheids run parallel with this diameter it follows that sampling with a borer at an acute angle produces a considerable increase in the number of uncut tracheids in the core.

The results in Table 1, show that with decreasing angle of boring the number of uncut tracheids increases significantly, such that the number present in the core taken at 35 degrees is about four times greater than that in the core taken at the normal angle of 90 degrees. Furthermore, within each treatment—angle core the number of full length tracheids is consistently higher in the 10th growth ring than in the 5th growth ring from the bark. This might indicate that there is a greater number of shorter uncut tracheids present in the 10th ring position than in the 5th ring position.

TABLE 1

The numbers of Uncut Tracheids at 4 different angles of Boring

Treatment Angle	90°		45°		40°		35°	
Rings from Bark	5	10	5	10	5	10	5	10
Totals	45	74	108	121	167	192	209	227
	119		229		359		436	

2. A Comparison of Core and Disc samples for Tracheid Length assessment.

It was found that in the case of growth rings from the disc sample 3 slides per ring were sufficient to supply the required sample of 45 tracheids. In the case of the core sample 6 slides per ring were required, the reason being the relatively greater amount of cut tracheids present.

Statistical analysis showed that for each growth ring sampled no significant difference in mean tracheid length existed between disc and core samples.

3. Distribution of Tracheid Length in a stem of Sitka spruce

The maximum mean tracheid length occurs in the 20–25 ring class from the pith at the 30% height level. The minimum occurs in the 0–5 ring class from the pith at the 70% and 80% height levels.

Variation is traced as illustrated in Fig. 1.

(a) *Variation in Tracheid Length with Age*

From Fig. 1. Tracheid Length versus % Height for the 6 ring classes from the pith, it is evident that in all 8 discs tracheid length increases with age from the pith.

(b) *Variation in Tracheid Length with Height*

Generally, tracheid length in each ring class increases and reaches a maximum value between 30% and 50% height in the stem. Only in the ring class (0–5) does it present a marked continual decrease.

(c) *The Effect of Rate of Growth on Tracheid Length*

At the 10% height level tracheid length shows a significant negative correlation with ring width. Table 2 shows a marked continual decrease.

simple order correlations are significant.

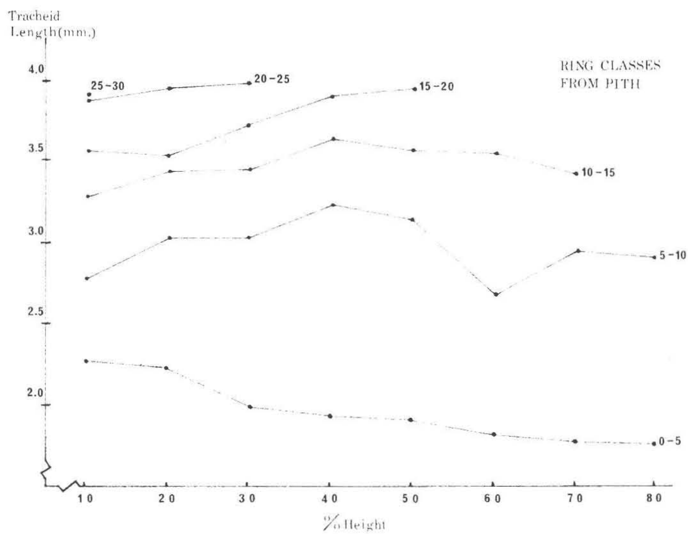

Figure 1: Relationship between tracheid length and per cent height for each ring class for the pith.

TABLE 2

Correlation coefficients between Tracheid Length, Age from the pith and Ring width at the 10% height level in a stem of Sitka spruce

Statistic	Correlation Coefficient	Level of Significance
Tracheid Length/Ring Width	—0.8133	5%
Tracheid Length/Age	+0.9710	1%
Age/Ring Width	—0.8459	5%

4. Distribution of Density in a stem of Sitka spruce

Table 3 presents the results obtained from the east side of the tree in the horizontal and vertical directions. It can be seen that the 10% height level density values (kg/m³) for the selected growth rings, increase generally, from pith to bark. In the vertical direction, in the 7th growth ring from the pith density increases from 281 kg/m³ at the 10% level to 364 kg/m³ at the 40% height level, decreases and rises again to reach it's maximum value of 386 kg/m³ at the 70% height level.

TABLE 3
Distribution of Density (kg/m³) in a stem of Sitka spruce

Rings from the Pith	% Height							
	10	20	30	40	50	60	70	80
4	256							
7	281	349	364	364	306	314	386	343
12	276							
17	325							

5. The Effect of East and West sampling on Density (kg/m³) in a stem of Sitka spruce

Analyses of variance of the effect of east and west sampling on density for both the horizontal and vertical directions, show that there is a statistically significant difference (at the 5% level in the horizontal direction and at the 1% level in the vertical direction) between east and west density values in the tree sampled. These analyses showed also that there were significant differences in density values from pith to bark and also with increasing height in the stem at the 5 and 1% levels of significance respectively. Results and analyses are presented in Tables 4 and 5.

TABLE 4
A comparison of East and West Sampling for Density (kg/m³) with increasing height in the stem

Direction	% Height							
	10	20	30	40	50	60	70	80
East	281	349	363	363	306	314	386	343
West	301	389	408	398	392	385	426	403

Analysis of Variance

Source	df	Mean Square	F
Height	7	23.83	10.605***
East/West	1	98.90	44.004***
Error	7	2.24	

***=Significant at 1% level.

TABLE 5
A comparison of East and West sampling for density (kg/m^3) with increasing ring number from the Pith

	Ring Number from Pith			
Direction	4	7	12	17
East	256	281	276	325
West	275	301	321	385

Analysis of Variance

Source	df	Mean Square	F
Rings	3	89.90	41.85**
Direction	1	25.45	11.85**
Error	3	2.14	

**=Significant at 5% level.

6. The Influence of Tree Spacing on Tracheid Length in Sitka spruce

In the design of this experiment it was considered unlikely that there would be any difference in wood properties due to spacing until the closest spacing, 2.4×2.4 metres (8×8 feet) had closed canopy. This was thought to be at approximately 7 years after planting. Hence, the corresponding growth rings near the pith were ignored. It was, furthermore, thought that differences in wood properties between the various spacings would be most likely to occur as the plantations closed canopy. Hence, in the examination of tracheid length only 2 annual growth rings, i.e. the 5th and 10th rings from the bark were examined. Any variation in tracheid length due to spacing should, theoretically, be found in those rings.

The experimental design was a 3×2 factorial. Factor S was spacing at three levels, one for each spacing. Factor R was growth rings from the bark at two levels, one for each growth ring sampled. Fifteen trees were sampled per spacing.

Despite the non-significant results obtained on comparing disc and core samples for mean tracheid length it was decided to utilise a bias correction factor proposed by Hart & Hafley (1967) to achieve a relatively unbiased estimate of the tracheid length population mean. This factor used the variance of each calculated mean tracheid length.

$$U = L + B.$$

where, $$B = \frac{S^2}{C-L} \frac{(k^2+1)}{(k^2-1)}$$

when, $$k = \frac{C-L}{S}$$

where, U = Unbiased estimate of the mean of the tracheid length population.
L = Sample mean tracheid length.
B = Bias estimate in sample mean.
S^2 = Sample variance.
S = Sample standard deviation.
C = Average chord length of the radially trimmed core (Found to be 7 m.m. in material used).

Mean tracheid length (m.m.) was based on a sample of 50 randomly selected tracheid lengths. The calculated B value varied from 0.01 to 0.05 m.m. For example, a sample with a mean of 2.43 m.m. and a standard deviation of 0.90 acquires a B value of 0.02 and becomes 2.45 m.m.

Results are presented in Table 6. The value in each cell is the mean

TABLE 6

The Influence of Tree Spacing on Tracheid Length in Sitka spruce

Rings from Bark	Spacing (m) 2.4×2.4	3.6×3.6	4.57×4.57
5th	2.95	2.94	3.08
10th	2.62	2.52	2.57

Each figure is the mean of 15 trees per spacing.

Analysis of Variance

Source	df	Mean Square	F. Value
Spacing (S)	2	0.074	1.61 n.s.
Rings (R)	1	4.003	87.02***
S/R Interaction	2	0.059	1.28 n.s.
Error	84	0.046	

n.s.: not significant
***: significant at 1% level.

of the fifteen corrected mean tracheid length values per ring per spacing. Statistical analysis showed that varying initial spacing in this plantation had no effect on mean tracheid length.

Between ıings, mean tracheid length differences were found to be significant at the 1% level while there was no significant interaction between factors.

7. The Influence of Tree Spacing on Density (kg/m^3) in Sitka spruce

In the same cores from which the 5th and 10th growth rings from the bark were selected for tracheid length assessment, the interval of growth rings i.e. the 6th to the 9th was, in one piece, assessed for density. The experiment had a completely randomised design. However, 4 cores were found unsuitable due to being twisted or broken.

Consequently, the data were analysed using Harvey's Least Squares Analysis of Data with Unequal Sub-Class Numbers (Kelleher, 1975). The results, presented in Table 7, show that spacing had a statistically significant effect (at the 1% level) on wood density.

TABLE 7

The Influence of Tree Spacing on Density (kg/m^3) in Sitka spruce

Spacing (m)	2.4×2.4	3.6×3.6	4.57×4.57
Density (kg/m^3)	389	310	281

Aanlysis of Variance

Source	df	Mean Square	F. Value
Spacing	2	284.05	15.26***
Error	38	25.16	

*** = significant at 1% level.

Discussion

While considerable details are available concerning tracheid length and density in wood, there is little information as regards the influence of silvicultural practices, such as tree spacing, on these wood properties. The experiment reported in this paper on the influence of spacing on tracheid length in Sitka spruce detected no statistically significant effect on tracheid length. It is possible ,however, that sampling for tracheid length within the growth ring was of insufficient intensity to estimate the mean with sufficient precision to detect small differences. At the 3.6×3.6 m. spacing approximately 60% of the total variation was due to tracheid length variation within the growth ring.

Spacing appears, from these experiments, to have a highly significant effect, in this plantation, on wood density. As can be seen in Table 7 mean density decreased with increasing spacing. Because of the method of sampling used in these experiments it is not possible to say at what stage of growth this difference becomes apparent. A sampling to take annual growth rings closer to the bark, and rings further from the bark in addition to those sampled in this study, would provide considerably more information on this aspect of wood density variation.

The information presented here does suggest that spacing and canopy closure have an effect on wood density. If this is true, then it could be expected that this variation would normally disappear either, (1) as the more closely spaced trees are thinned, or (2) as the wider spaced trees close canopy.

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