Prediction of whole-tree radiata pine kraft tracheid/fibre length from pith-to-bark strips taken 1.4 m from ground

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SUMMARY

The length of fibres with both ends intact (tracheids) and the length-weighted fibre length (Kajaani FS 200) were determined for twenty-five 15-year-old radiata pine trees. Whole-tree kraft tracheid and fibre length values were determined from kraft pulps whereas those for the pith-to-bark strips were determined from macerated 3-growth-layer sets.

Estimates of whole-tree kraft tracheid/fibre length can be predicted from corresponding measurement of macerated complete or selected growth-layer groupings of pith-to-bark strips taken at 1.4 m from ground. Prediction error is dependent on numbers of pith-to-bark strips taken from each tree, the number and age range of 3-growth-layer sets assessed per strip, compression wood content, and the measurement procedure used.

Keywords

Tracheid, kraft fibre, growth-layer sets, whole-tree prediction, radial strips, compression wood

Tracheid length patterns and distributions within trees, and levels of variation among trees of the same age and growing site are well documented for both radiata and loblolly pine (*1,2,3*). The need is to be able to describe seedlings and standing trees according to their fibre length, and other microstructure and chemical descriptors, and to be able to predict mature tree properties at the earliest possible age (*4*). This necessitates that non-destructive sampling and testing procedures be used.

In this paper, the variation in tracheid/fibre length within and among trees, and the prediction of whole-tree kraft values, are assessed for each of twenty-five 15-year-old radiata pine trees. Each whole-tree kraft tracheid/fibre length estimate is based on two pith-to-bark strips taken 1.4m from the ground.

Note:

1. Pith-to-bark strips were cut from discs taken 1.4 m from the base of the butt-logs. This is the traditional breast-height sampling point used to assess the wood properties (wood density in particular) of standing trees (*1*).
2. The term tracheid refers to fibres with both ends intact whether they are in the macerated wood samples or the whole-tree kraft pulps.
3. The term fibre can refer to all particles of fibre origin (intact and shortened fibres, fibre fragments and fines) present in the macerated wood samples or the whole-tree kraft pulps.

EXPERIMENTAL

Tree selection procedure

Seven trees from each of 25 open-pollinated families of radiata pine, growing in a 15-year-old progeny test at Rotoehu Forest (38°57′S, 175°37E), were originally selected from the 170 families in the test, on the basis of their female parent trees' tracheid perimeter and wall thickness (*5,6*).

Both tracheid length (*8*) and Kajaani FS 200 fibre length were then assessed from 10 mm cores (taken at 1.4 m above ground) from each of the seven trees of each family, 175 samples in all. The edges of each core were 'shaved' parallel-to-the-grain with a preset bandsaw, and tracheid and fibre length determined on the outer five growth layers, macerated using peracetic acid, as described below (*7*).

Correlations between the two length measurement procedures were moderate, with $r^2 \approx 0.65$. Levels of correlation were increased slightly by truncating the distribution curves and excluding short fibre and fines from the FS 200 length estimates. The Kajaani FS 200 length-weighted fibre length values were therefore used in the tree selection process since the measurement error was smaller than the tracheid length procedure, on account of the large numbers of fibres measured by the Kajaani FS 200.

The 175 trees were allocated to five length-weighted length classes spanning the range of breast-height outerwood fibre length measurements. Four to six trees were selected from each fibre length class, with the objective of obtaining a wide range of tracheid wall thickness and perimeter within each class, with the constraint of selecting only one tree from each of the 25 open-pollinated families. Some compromises were required to include trees with outlying values of tracheid wall thickness and perimeter.

The 25 trees were then felled and discs removed at 1.4 m above ground level, from which pith-bark strips were sawn (see below). After further disc sampling, the trees were whole-tree chipped for a kraft pulping study (unpublished data).

Tracheid and fibre length measurement of the 25 selected trees

Two pith-to-bark strips were cut from the breast-height (1.4 m) discs to give two radial strips (randomly assigned labels of A and B) for each of the 25 trees. Each radial strip was cut with the same longitudinal (15 mm) and tangential (10 mm) dimensions using a preset band saw. The pith-to-bark strips from each disc were selected to have the lowest possible compression wood content, and to have maximum radial separation from each other. Each radial strip was broken into five separate lots: the outer three growth layers, the next 3 lots of 3 growth layers, and the innermost lot containing from 1 to 3 growth layers. This division resulted in ten growth-layer sets for each tree. Thus, 10 samples for each of the 25 trees, or 250 samples in total were macerated and both tracheid length and Kajaani FS 200 length-weighted fibre length determined as follows:

- Tracheid lengths were measured using a map measuring wheel and a modification of the Harris procedure (*7*).

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Table 1
Among-tree and error variance components for the tracheid lengths and fibre length for each growth-layer set.

Growth-layer set	Mean length* (mm)	Total variance (mm²)	Among-tree variance component** (mm²)	Error variance component ** (mm²)	Among-tree cv *** (%)	Error cv *** (%)
Kajaani FS200 length-weighted fibre length						
Set 1 (layers <4)	1.42	0.0142	0.0110	0.0031	7.4	3.9
Set 2 (layers 4-5)	2.09	0.0355	0.0255	0.0100	7.6	4.8
Set 3 (layers 7-9)	2.70	0.0463	0.0342	0.0121	6.8	4.1
Set 4 (layers 10-12)	2.96	0.0772	0.0527	0.0245	7.8	5.3
Set 5 (layers 13-15)	3.11	0.0786	0.0300	0.0486	5.6	7.1
Map wheel tracheid length						
Set 1 (layers <4)	1.91	0.0417	0.0134	0.0283	6.1	8.8
Set 2 (layers 4-5)	2.43	0.0525	0.0305	0.0220	7.2	6.1
Set 3 (layers 7-9)	3.09	0.1108	0.0679	0.0429	8.4	6.7
Set 4 (layers 10-12)	3.30	0.1377	0.0897	0.0480	9.1	6.6
Set 5 (layers 13-15)	3.44	0.1347	0.0643	0.0703	7.4	7.7

* Mean length-weighted fibre length for Kajaani FS200 measurements, or mean average tracheid length for map wheel measurements.
** The error variance component is based on the between-paired-strip variation and the analytical error combined.
*** CV%: coefficient of variation calculated from variance components and growth-layer set mean lengths

30 tracheids with two intact and identifiable ends were measured by each of two observers for each of the 250 samples. Where the difference between the two observers was >5%, samples were remeasured. Additional observers were used until two observers agreed to within 5%. A maximum of four observers were used to obtain the mean tracheid length of any one sample. Levels of variation among observers were high and actual tracheid length values used are the least square means to minimise observer bias.

- Kajaani length-weighted fibre lengths were determined following Tappi method T271 pm-91. At least two replicate measurements were made for each sample (from the same slurry), and these were accepted if recorded length-weighted fibre length values differed by < 0.03 mm. Kajaani FS 200 fibre length refers to all particles detected by the analyser (shortest class is 0.00 to 0.05 mm) irrespective of damage etc. By using the length-weighted fibre length as the method of weighting instead of average length (i.e. frequency weighted) the influence of fines and small particles on the result is reduced.

Following the same measurement procedures on the map wheel and Kajaani FS200, tracheid and fibre length determinations were made on the kraft pulps (at Kappa 30±2) prepared from the whole-tree kraft chip samples of each of the 25 trees.

RESULTS AND DISCUSSION

Tracheid and fibre length variation among and within trees at 1.4 m

Tracheid/fibre lengths increase with increasing distance from the pith for both the map wheel and Kajaani FS 200 measurement procedures (Table 1), as expected (*1*). Tracheid lengths measured with the map wheel are longer than corresponding fibre length values, determined with the FS 200 instrument, since only tracheids with both ends intact are measured. In contrast, both intact and broken fibres as well as fibre fragments are included in the FS 200 measurement. These differences in measurement are partly compensated for by using length weighting for the Kajaani

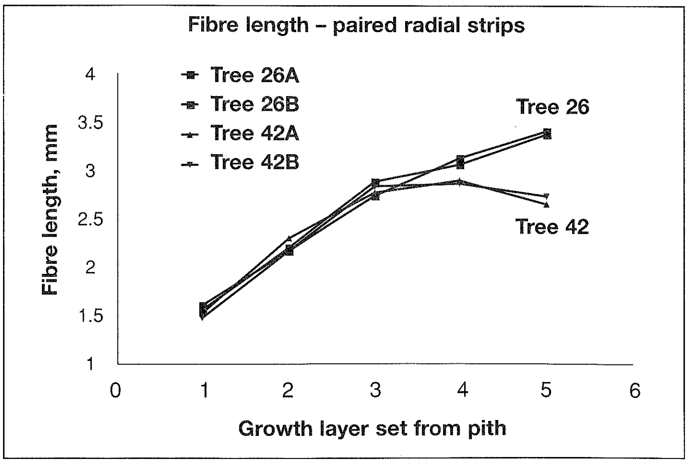

Fig. 1 FS 200 fibre length versus growth-layer set from pith for paired radial strips from trees 26 and 42. Note the very similar traces for the paired strips from each tree. Each growth-layer set consists of fibres from three consecutive growth layers.

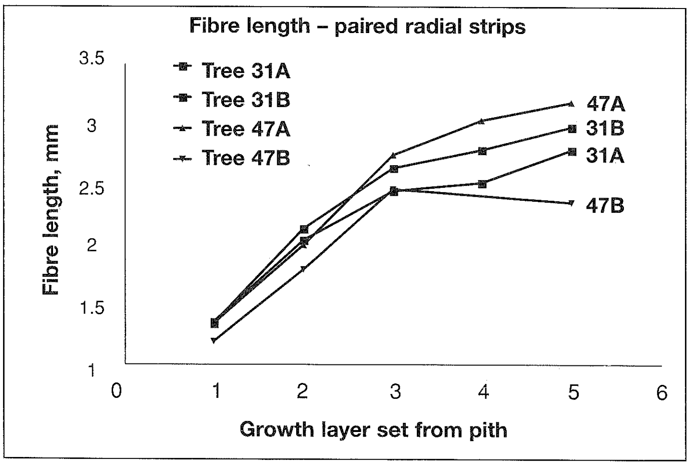

Fig. 2 FS 200 fibre length versus growth-layer set from pith for paired radial strips from trees 31 and 47. Note the increased levels of divergence between the strips for each tree with increasing growth-layer set number for the paired traces of each tree. Each growth-layer set consists of fibres from three consecutive growth layers.

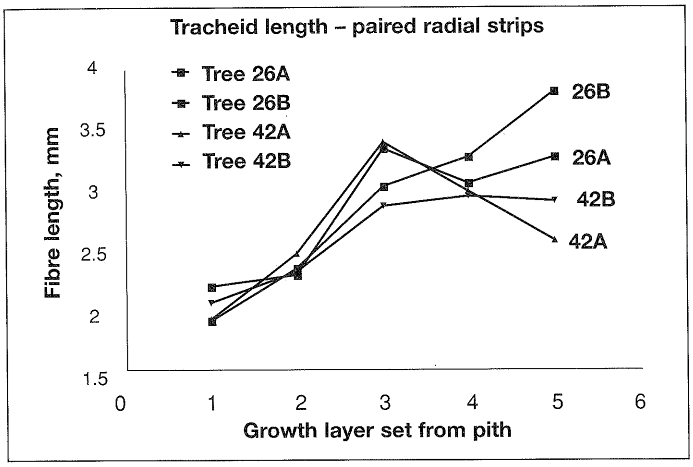

Fig. 3 Map wheel tracheid length versus growth-layer-set-number from pith for paired radial strips from trees 26 and 42. Note the high random variation in the outer growth-layer sets for the paired strips of trees 26 and 42 compared with those for FS 200 fibre length (Fig. 1). Each growth-layer set consists of fibres from three consecutive growth layers.

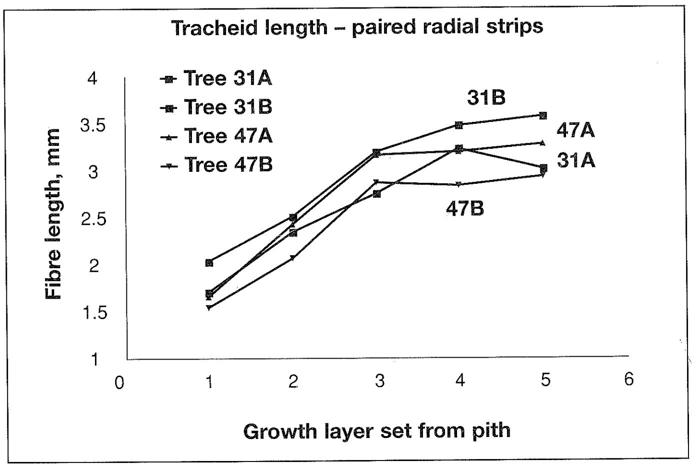

Fig. 4 Map wheel tracheid length versus growth-layer-set-number from pith for paired radial strips from trees 31 and 47. Note the high divergence between the strips for each tree and high random variation, at all growth-layer-set-numbers, for the paired strips of trees 31 and 47 compared with those for FS 200 fibre length (Fig. 2). Each growth-layer set consists of fibres from three consecutive growth layers.

Table 2
Correlation matrix for fibre (FS200) and tracheid (map wheel) length means – 5 x 3-layer growth-layer sets (average of both sides).

Growth-layer set	1 (Layers <4)	2 (Layers 4-6)	3 (Layers 7-9)	4 (Layers 10-12)	5 (Layers 13-15)
		Fibre length (FS 200)			
1	1	0.66	0.44	0.30	0.44
2		1	0.78	0.66	0.65
3			1	0.85	0.66
4				1	0.75
5					1
		Tracheid length (map wheel)			
1	1	0.46	0.38	0.27	0.29
2		1	0.58	0.38	0.50
3			1	0.79	0.68
4				1	0.71
5					1

FS200 fibre length and arithmetic averages for the map wheel tracheid length.

Magnitudes of the error variance component (between radial strips plus analytical error) increase with increasing growth layer number from the pith, and are greater for tracheid average length measured with the map wheel than for length-weighted fibre length measured with the Kajaani FS 200 (Table 1). The increase in error variance component from pith-to-bark occurs because of larger differences between radial strips for the outer growth-layer sets. The larger error coefficient of variation for the map wheel compared to the FS 200 is because of larger analytical errors that arise because of the small number of tracheids measured on the map wheel. The magnitudes of the length measurements are different since the FS 200 and map wheel use different measurement criteria and weightings to calculate mean lengths. Among-tree variance component coefficients of variation for the FS 200 and map wheel procedures were similar (Table 1).

The increase in fibre length with increasing growth layer number from pith is demonstrated in both Figures 1,2. The paired sets of data of Figure 1 (trees 26 and 42) and Figure 2 (trees 31 and 47) show respectively low and extreme levels of divergence between the strips for each tree with increasing growth-layer set from the pith. Levels of non-systematic variation are substantially higher for the tracheid than for the fibre measurements for the four sets of paired traces – trees 26, 42, 31 and 47 (Fig. 3, 4). The cause of the non-systematic variation is probably random analytical error in the average tracheid length arising because of the small number of tracheids measured.

Tracheid and fibre length relationships between growth-layer sets

Correlations among fibre or tracheid lengths of inner and outer growth-layer sets are least for the growth-layer set closest to the pith (Table 2). Furthermore, correlations are high among the outer growth-layer sets and higher for the FS200 fibre than for the map wheel tracheid measurements. The low correlations between fibre lengths (Kajaani FS200) of set 1 and sets 2, 3, 4 and 5 are explained in part by a low length variation among trees for the innermost set 1 data (Fig. 5). Fibre length ranges from 1.16–1.62 mm for growth-layer set 1 and 1.71–2.4 mm for growth-layer set 2. A high proportion of parenchymatous tissue in the innermost growth layer could account in part for the low among-tree variation in FS200 fibre length of growth-layer set 1. For the map wheel tracheid length measurement, on the other hand, the among-tree variation for growth-layer set 1 is only slightly lower than for set 2 (Fig. 6). The map wheel tracheid length procedure measures tracheid with two intact ends only and hence gives results that are not influenced by a high proportion of parenchymatous tissue in the innermost growth layer. Despite the direct measurement of tracheid length, the values obtained for the inner growth-layer set 1 are poorly correlated with those of outer growth-layer sets (Table 2).

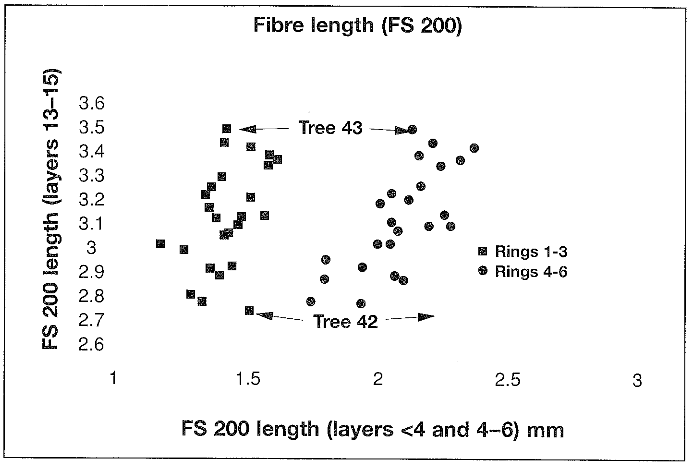

Fig. 5 Mean fibre lengths of 25 trees - growth-layer set 5 (layers 13–15) versus set 1 (layers < 4) and set 2 (layers 4–6).

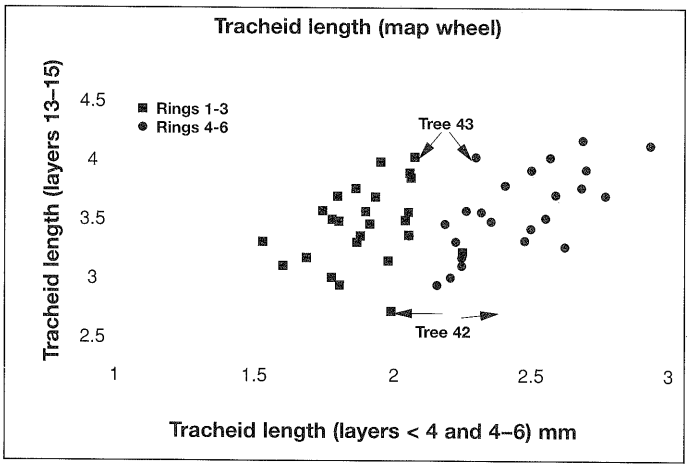

Fig. 6 Mean tracheid lengths of 25 trees - growth-layer set 5 (layers 13–15) versus set 1 (layers < 4) and set 2 (layers 4–6).

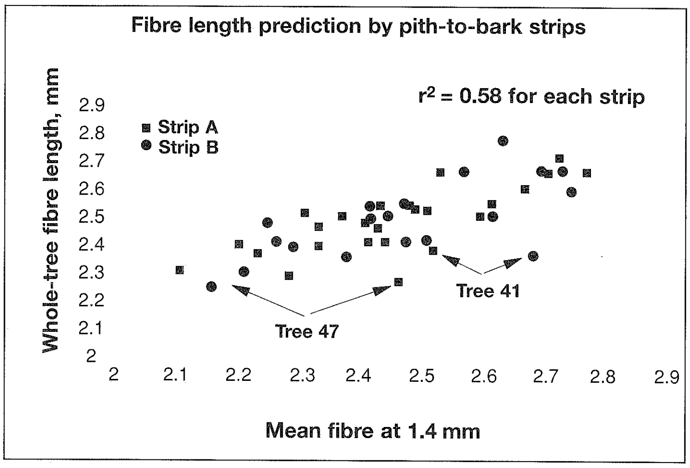

Fig. 7 Whole-tree kraft fibre length versus fibre length of paired pith-to-bark strip for each of 25 trees. The pith-to-bark values used are the calculated averages for growth-layer sets 1, 2, 3, 4 and 5. The paired values for trees 41 and 47 are indicated showing the outer position of one strip of each pair.

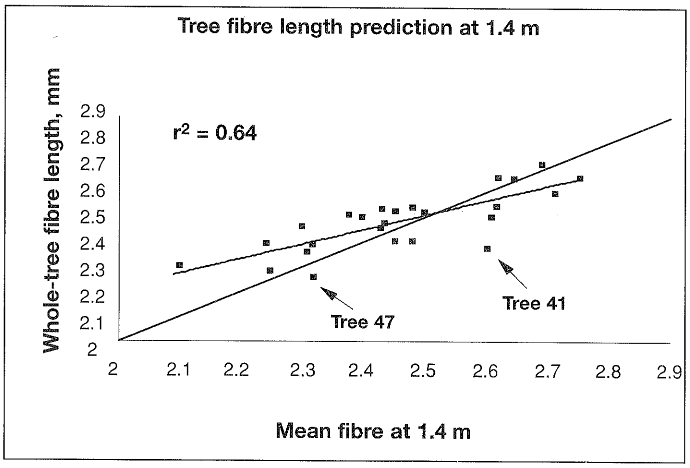

Fig. 8 Whole-tree kraft fibre length versus the mean fibre length of paired pith-to-bark strip for each of 25 trees. The pith-to-bark values used are the averages of both sides and growth-layer sets 1, 2, 3, 4 and 5. Mean values for trees 41 and 47 are indicated. The diagonal line is the line of equal value of pith-to-bark and whole-tree fibre length.

Correlations between growth-layer sets 1 and 5 are relatively low for both fibre length and tracheid length. Correlations are higher between sets 2 and 5, and are higher still between sets 3 and 5, and 4 and 5 (Table 2). Tree 42 shows consistently low fibre length values of growth-layer sets 1 and 2, and tree 43 consistently high fibre length values (Fig. 5). These apparent outliers lower the fibre length correlations between sets 1 and 5, and 2 and 5. For the tracheid length data, similar outlier trends occur for tree 42, and for tree 43 the value for growth-layer set 2 is an apparent outlier (Fig. 6).

Prediction of whole-tree kraft fibre and tracheid length from strips at 1.4 m

This section examines the relationships between whole-tree kraft pulp fibre and tracheid lengths and the fibre and tracheid lengths of breast-height pith to bark growth-layer sets.

Correlations between whole-tree kraft fibre length prediction, from the FS 200 length values of 3-ring growth-layer sets taken 1.4 m from ground, are lowest for growth-layer set 1 and similar for all other sets and set combinations (Table 3). Correlations are usually higher when based on the mean of the paired strips. Corresponding correlation coefficients from the map wheel tracheid length procedure are consistently lower. FS 200 fibre length values for growth-layer sets 2, 3, 4 and 5 are moderate predictors of whole-tree kraft fibre length (Table 3). Improved predictions are obtained by combining the fibre length data for consecutive outer growth-layer sets (2 and 3; 2, 3 and 4; 2, 3, 4 and 5; 3, 4 and 5; and 4 and 5). Hence, whole-tree kraft fibre length estimates for a 15-year-old tree can be obtained when the tree is 9 years old using the outer 6 growth-layers (sets 2 and 3). For a 15-year-old tree the outer 6-9 growth-layers can be used to predict the whole-tree kraft fibre length. The innermost growth-layer set is a relatively poor predictor of whole-tree kraft fibre length ($r = 0.52$), although levels of prediction are progressively improved with the merging of growth-layer data sets 1 and 2, and 1, 2 and 3 (Table 3). For example, the best estimate of whole-tree kraft fibre length is obtained with the inclusion of growth-layer set 1 using the paired pith-to-bark strips in total ($r = 0.80$).

The whole-tree kraft fibre length prediction relationship, from pith-to-bark strips taken at 1.4 m from ground for 25 trees, is shown for the Side A strips and

Table 3
Prediction of whole-tree kraft fibre and tracheid length from pith-to-bark growth-layer sets and combinations of growth-layer sets.

Predictor Growth-layer set	Correlation coefficient r Pith-to-bark Strip A	Pith-to-bark Strip B	Mean of Strip A & B
FS 200 length-weighted fibre length			
Set 1 (layers <4)	0.31	0.68	0.52
Set 2 (layers 4-6)	0.65	0.64	0.70
Set 3 (layers 7-9)	0.74	0.71	0.78
Set 4 (layers 10-12)	0.63	0.59	0.66
Set 5 (layers 13-15)	0.56	0.59	0.67
Mean of Sets 1& 2	0.59	0.71	0.69
Mean of Sets 1, 2 & 3	0.73	0.76	0.79
Mean of Sets 2 & 3	0.76	0.72	0.78
Mean of Sets 4 & 5	0.65	0.69	0.71
Mean of Sets 3, 4 & 5	0.72	0.73	0.77
Mean of Sets 2, 3, 4 & 5	0.75	0.74	0.78
Mean of Sets 1, 2, 3, 4, & 5	0.76	0.76	0.80
Tracheid length (map wheel)			
Set 1 (layers <4)	0.17	0.28	0.28
Set 2 (layers 4-6)	0.30	0.25	0.30
Set 3 (layers 7-9)	0.64	0.60	0.68
Set 4 (layers 10-12)	0.47	0.60	0.59
Set 5 (layers 13-15)	0.57	0.54	0.65
Mean of Sets 1& 2	0.28	0.31	0.34
Mean of Sets 1, 2 & 3	0.50	0.53	0.57
Mean of Sets 2 & 3	0.56	0.53	0.59
Mean of Sets 4 & 5	0.57	0.61	0.67
Mean of Sets 3, 4 & 5	0.66	0.64	0.70
Mean of Sets 2, 3, 4 & 5	0.64	0.62	0.68
Mean of Sets 1, 2, 3, 4, & 5	0.64	0.61	0.67

Side B strips in Figure 7. The coefficients of determination ($r^2 = 0.58$ for Side A and $r^2 = 0.58$ for Side B) are clearly lowered by the apparent outlier values of trees 41 and 47. Levels of prediction are improved ($r^2 = 0.64$) when average paired-strip fibre length values are used although those for trees 41 and 47 still appear as apparent outliers (Fig. 8). These wide differences between the paired pith-to-bark strips of both tree 41 and tree 47 are confirmed by corresponding differences for growth-layer sets 2, 3, 4 and 5 (Fig. 9). Although wide differences occur for the paired pith-to-bark strips of trees 41 and tree 47, their apparent outlier status could also be explained by exceptionally low whole-tree kraft fibre length values (Fig. 7, 8). The fibre length outlier trends for tree 47 are also shown for the tracheid length data set, whereas those for tree 41 occur with the fibre length data set only.

The slope of the length regression of Figure 8 requires comment. Whole-tree kraft values are longer than pith-to-bark means at 1.4 m for short-fibred trees, and slightly shorter for long-fibred trees. This could indicate selective shortening by chipping for long-fibred trees and/or a trend in the spatial pattern of variation within trees.

Correlation coefficient values listed in Table 3 are based on fibre and tracheid length values determined for separately macerated 3-layer growth-layer sets, and their unweighted average for each pith-to-bark strip. Thus, any influence of the radial proportion of any growth-layer set is excluded, as is the influence of area weighting the strip to account for the circular cross-section of a tree stem. When these analyses were carried out for pith-to-bark strip averages weighted by growth-layer set radial proportion or area proportion, levels of correlation and prediction were similar to, or less than, those obtained with the unweighted averages for pith-to-bark strips.

Explained variation in whole-tree kraft fibre length (i.e. r^2 value) is estimated to decrease by approximately 10% when only one strip is used instead of the mean of two strips (Table 4). Note that the percentage change in r^2 and the variance components used to calculate it are estimates based on the 25-tree sample of this study.

Compression wood influences

The high level of compression wood in New Zealand's radiata pine resource can be expected to adversely affect the prediction of whole-tree kraft fibre properties using pith-to-bark cores taken at 1.4 m. All four critical wood microstructure descriptors (fibre cross-section dimensions, length, microfibril angle and chemistry) are expected to be strongly influenced by levels and distributions of compression wood in standing trees (*4*). Compared to normal wood, compression wood fibre length and diameter are decreased, microfibril angle is increased, and lignin and carbohydrate contents are respectively increased and decreased (*8,9*). The method used to quantify compression wood in these samples was based on visual assessment of the proportion of the disc cross-section area discoloured. Values for

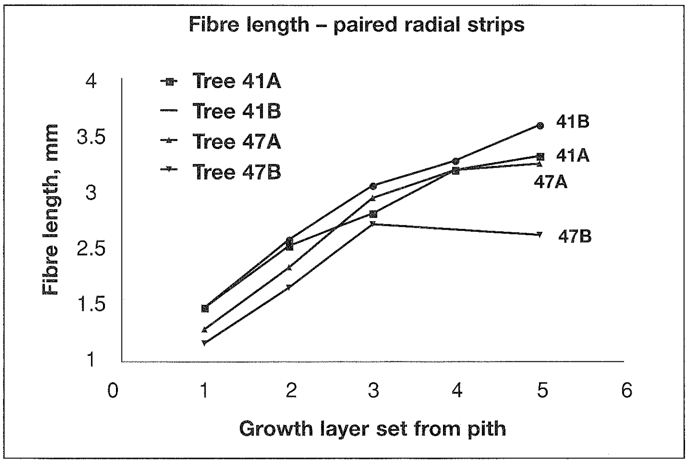

Fig. 9 **FS 200 fibre length versus growth-layer-set-number from pith for paired radial strips from trees 41 and 47. Note the increased levels of divergence with increasing growth-layer-set-number for the paired traces of each tree. Each growth-layer set consists of fibres from three consecutive growth layers. Trees 41 and 47 are outliers in the prediction of whole-tree fibre length from pith-to-bark strips.**

Table 4
Estimated percentage decrease in whole-tree kraft fibre length prediction (r^2) from using one rather than two pith-to-bark strips.

Growth-layerset combination	Among trees variance component (mm^2)	Error variance component (mm^2)	Estimated r^2 decrease for one strip only * (%)
3, 4 and 5	0.0384	0.01000	10.3
2, 3, 4 and 5	0.0329	0.00747	9.3
1, 2, 3, 4 and 5	0.0248	0.00510	8.2

*Per cent estimates of decrease in r^2 going from two radii measured per tree to one radius determined using the expression: $100 \times (\sigma_e^2/2) / (\sigma_x^2+\sigma_e^2)$.

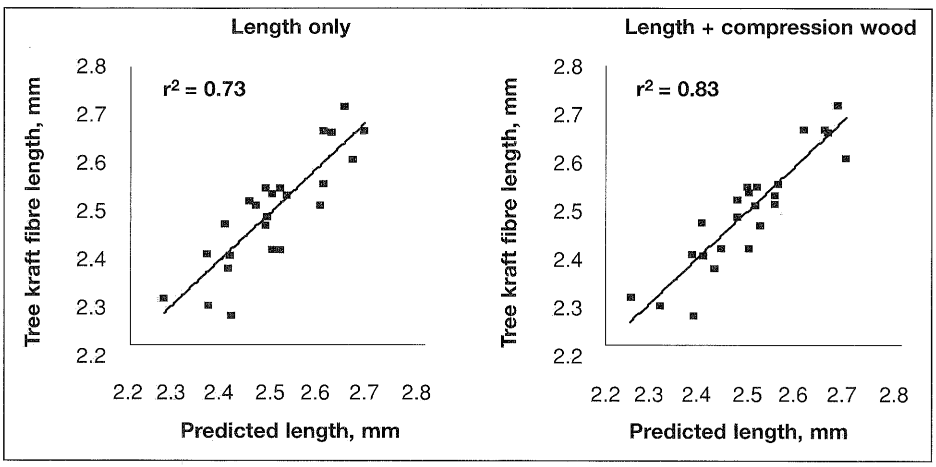

Fig. 10 Measured whole-tree kraft fibre length versus model-predicted whole-tree kraft fibre length. Model-predicted values are based on pith-to-bark cores at 1.4 m without compression wood (r^2 = 0.73 and root mse = 0.064 mm) and with whole-tree compression wood included in the regression model (r^2 = 0.83 and root mse = 0.053 mm). Note: tree 41 data are excluded from the analyses because of their apparent outlier status with the corresponding r^2 values increasing from 0.64 to 0.73 (see also Fig. 8).

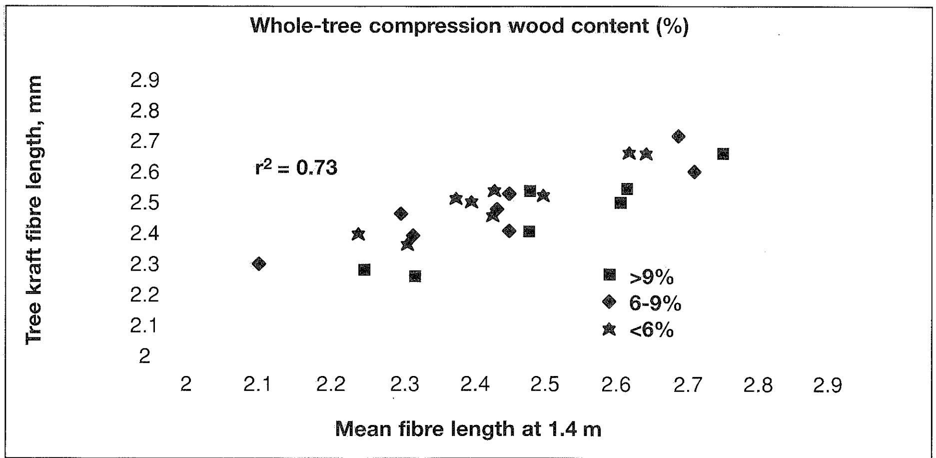

Fig. 11 Influence of compression wood content on prediction of whole-tree kraft fibre length from paired pith-to-bark strips taken at 1.4 m from twenty-four 15-year-old radiata pine trees (Tree 41 data omitted see Fig. 10).

discs were weighted by volume to derive log and whole-tree kraft values.

Compression wood has a strong influence on the prediction of whole-tree kraft fibre length from pith-to-bark strips taken at 1.4 m from ground (Fig. 10, 11). Trees with compression wood contents >9% contain fibres that are generally shorter, for a given fibre length at 1.4 m from the ground, than those of low compression wood content, <6% (Fig. 11). The inclusion of whole-tree kraft compression wood contents in the regression relationship lowers the unexplained variation from 27 to 17% (r^2 increases from 0.73 to 0.83 for the 24 sample data set – tree 41 excluded) (Fig. 10). In the multiple regression model the p-values for the two independent variables were 0.0001 for the mean fibre length of growth layer sets 1 to 5, and 0.0027 for whole-tree compression wood. With compression wood included in the predictive model the percentage variation explained in whole-tree kraft fibre length is high and similar to the per cent variation explained with a data set of 13-year-old trees for predicting whole-tree kraft density from outerwood density (*6*). Tracheid lengths determined using the traditional procedure of Harris (*7*) show markedly higher levels of unexplained variation (Fig. 12), but they show a similar improvement in prediction of whole-tree kraft values when compression wood is included in the model. The multiple regression model for tracheid length had p-values for the two independent variables of 0.0001 for the mean tracheid length of growth layers 1 to 5 and 0.0011 for whole-tree compression wood. The same macerated samples were used for tracheid and fibre length measurements (Fig. 10, 12).

CONCLUSIONS

Whole-tree kraft fibre length can be predicted from the fibre length obtained from macerated pith-to-bark strips taken at 1.4 m from ground. The explained variation is dependent on numbers of pith-to-bark strips taken from each tree, the number and age-range of growth-layer sets assessed per strip, compression wood content, and the measurement procedure used.

The following are the conclusions for this study with its twenty-five 15-year-old radiata pine trees, which were whole-tree chipped and kraft pulped, with two pith-to-bark strips at 1.4m from each tree, each separated into 3-layer growth-layer groupings, and two measurement procedures.

- Variation among trees and within trees (between the radial strips at 1.4 m plus analytical error) increase in magnitude with increasing distance from the pith for both the fibre length (FS 200) and tracheid length (map wheel) procedures.
- Among-tree variance component coefficient of variation values are similar for the FS 200 and map wheel procedures. Error variance coefficient of variation values are larger for the map wheel procedure than the FS200 procedure.
- The innermost growth-layer set of pith-to-bark strips at 1.4 m is a poor predictor of whole-tree kraft length.

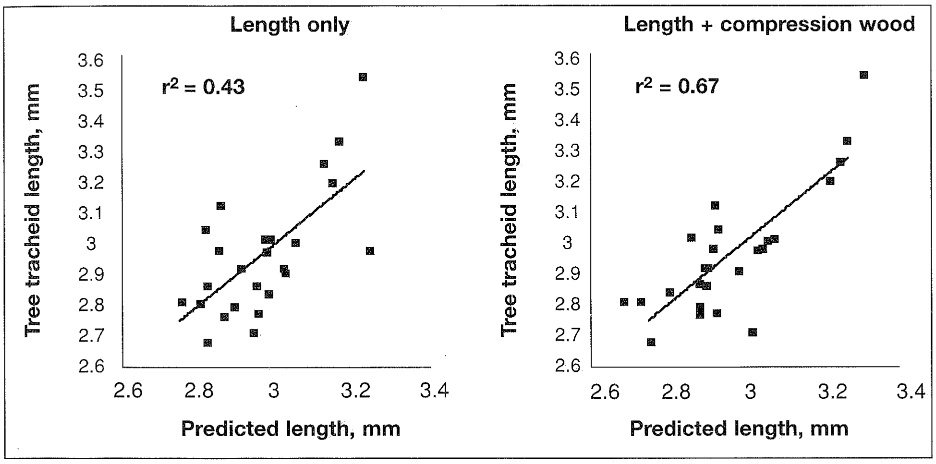

Fig. 12 Measured whole-tree kraft tracheid length versus model-predicted whole-tree kraft tracheid length. Model-predicted values based on pith-to-bark cores at 1.4 m without compression wood (r^2 = 0.43 and root mse = 0.152 mm) and with whole-tree compression wood included in the regression model (r^2 = 0.67 and root mse = 0.121 mm).

Predictability is better with the other four outer growth layer sets. All of the outer four growth-layer sets are roughly similar predictors of whole-tree kraft length.

- Improved predictions are obtained by combining the fibre length data for consecutive outer growth-layer sets (2 and 3; 2, 3 and 4; 2, 3, 4 and 5; 3, 4 and 5; and 4 and 5). Hence, whole-tree kraft fibre length predicted values for a 15-year-old tree can be obtained when the tree is 9 years old using the outer 6 growth layers (growth-layer sets 2 and 3). For a 15-year-old tree the outer 6-9 growth layers can be used to predict the whole-tree kraft fibre length. This is useful information because cores taken from standing trees can easily miss the innermost growth layers.
- The best prediction of whole-tree kraft fibre length is obtained with total pith-to-bark strip where the innermost growth-layer set is used in combination with the outer 4 sets. Inferior predictions are obtained using the innermost growth-layer set only or the inner two growth-layer sets in combination one with another.
- Predictability is roughly the same when the pith-to-bark fibre length values are based on the average of growth-layer sets 1-5, or a weighted average using the radial proportion of each strip, or an average weighted by the proportional area of each growth-layer set in the disc cross-section.
- Whole-tree predictions from pith-to-bark strips have markedly lower r^2 values for tracheid length measured with the map wheel, than the r^2 values for fibre length measured with the Kajaani FS200.
- Whole-tree kraft fibre length prediction r^2 are decreased by about 10% when single strip values are used as predictors rather than duplicate pith-to-bark strips from each side of the tree.
- Predictions of whole-tree kraft fibre and tracheid lengths are strongly influenced by compression wood contents. When whole-tree kraft compression wood contents are taken into account fibre length r^2 values are increased from 0.73 to 0.83.

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