PHYSIOLOGICAL AGEING AND SITE EFFECTS ON WOOD PROPERTIES OF *PINUS RADIATA*

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ABSTRACT

Effects of physiological ageing on physical wood properties of *Pinus radiata* D.Don trees were assessed. In the first trial, seedlings and cuttings propagated from 1- to 5-year-old parent trees grown in field trials on two contrasting forest sites (Kaingaroa Forest—pumice, Tairua Forest—clay) were sampled at 11 years. The second trial involved 25-year-old seedlings and cuttings, physiologically aged 12 to 16 years, which were sampled in Kaingaroa Forest. Wood characteristics assessed were stem volume, wood density, heartwood development, spiral grain, compression wood, tracheid length, and corewood percentage.

In the trial with trees aged 11 years (physiological age ≤5 years), there were no significant differences or trends in wood properties associated with physiological age. However, the impact of site was significant for all wood properties measured. In the trial with trees aged 25 years (physiological age 12–16 years), aged cuttings had significantly lower wood density, longer tracheids in rings 2 and 5, and higher spiral grain angles in the first 14 rings when compared to seedlings.

Keywords: cuttings; seedlings; wood properties; wood density; spiral grain; tracheid length; *Pinus radiata*.

INTRODUCTION

It has been recognised for some time that cuttings can successfully be propagated from *Pinus radiata* trees at least up to 40 years of age (Thulin & Faulds 1968), and clonal forestry has been seriously considered for at least 30 years (Menzies *et al.* 1988). Early trials with cuttings showed that propagules from older trees (4–5 years and older) have shown slower early diameter growth but slightly improved stem form. For most situations physiologically juvenile cuttings are preferred, but on fertile sites where form is a consideration, cuttings with a physiological age of 3–4 years have been recommended (Menzies & Klomp 1988).

Research on vegetative propagules (cuttings) of *P. radiata* in Australia and New Zealand has shown that the physiological age of the parent material can have significant influence on wood properties (Nicholls & Brown 1971; Nicholls *et al.* 1974, 1977; Sweet & Harris 1976; Cown 1988). Nicholls & Brown (1971) found that cuttings from 9-year-old parents had longer tracheids, larger spiral grain angles, and lower density than their parents at the same age. Further work by Nicholls *et al.* (1977) found that cuttings with a physiological age of 12 years had decreased density and increased tracheid length and spiral grain, while cuttings with a physiological age of 7 years or less showed negligible effects on wood properties compared with the seedling material. Increasing the age of the tree (ortet) from which cuttings are taken beyond 7 years caused not only reduced stem growth but lower wood density and increased tracheid length and spiral grain. This age of 7 years was also found by Cown (1988) to produce no major differences in wood properties, while material from 15-year-old parents showed significant differences.

In a recent study on individual tree pulping (Kibblewhite & Uprichard 1995) kraft fibre properties of 11, 16-year-old, *Pinus radiata* clones (physiological age 5 years) were unexpectedly "mature" relative to seedlings. In general, pulp fibres were wider, larger, and of higher coarseness than expected and certain clones appeared to produce "slabwood-type" fibres (except for length) at an early age. This unexpected result was ascribed to an effect of physiological ageing on fibre characteristics of the cuttings.

The current study was proposed to yield more comprehensive information on the effect of various physiological ageing levels on *P. radiata* by including standard wood properties and sampling whole trees.

MATERIALS

No one trial was available which could provide material representing a comprehensive set of trees of different physiological ages, and so the study was split.

Trial 1 was designed to examine the effect of low levels of physiological ageing. It included open-pollinated seedlings plus cuttings of 1, 2, 3, 4, and 5 years physiological ageing from two sites—Kaingaroa Forest (Trial 1887, Compartment 367) and Tairua Forest (Trial A397/1, Pritchard's Block). All plants, seedlings and cuttings, were originally propagated from seed collected from open-pollinated "850" seed orchard clones with the same genetic ranking (GF12–14). The trees were planted in 1983 and sampled in 1994 using 10 trees from each ageing level from each site (10 trees × 6 treatments(ages) × 2 sites). Trials consisted of 12 replications of eight-tree-row plots. Mean diameter (dbhob) was calculated for each physiological age group and the 10 trees were selected around that mean. Breast height 5-mm increment cores were taken from each tree before felling, after which two 50-mm-thick wood discs were taken from heights 0, 1.4, 6.4, and 11 m.

The effect of advanced physiological ageing was investigated in Trial 2. This involved sampling from 10 parent clones and 10 corresponding open-pollinated families growing in Kaingaroa Forest (Trial R944/9, Compartment 1350) at age 25 years. Each parent clone was represented by one open-pollinated seedling and one cutting. Age of parent ortets at the time of propagation ranged from 12 to 16 years. Two 50-mm-thick discs were taken from the felled stems from heights 0, 1.4, and 6.4 m and at subsequent 5-m intervals up to a small-end diameter of 100 mm (averaging eight discs per tree).

METHODS

The increment cores were taken to calculate correlations between outerwood core and whole-tree density.

The following six wood properties were measured from the first of the two discs removed at each of the four sampling heights:

Stem volume: Both under- (dub) and over- (dob) bark diameters were recorded from the discs using diameter tapes, before and after bark removal. These measurements were used to calculate log and stem volumes. Bark thickness as a percentage of cross-sectional area was calculated from the difference between the dob and dub.

Heartwood percentage: The heartwood diameter of each disc was measured and expressed as a percentage of cross-sectional area.

Moisture content: Percentage moisture content was calculated from the green and oven-dry weights of each disc. Moisture content expresses the ratio of water to oven-dry wood.

Disc, log, and stem wood density: Green and basic (oven-dry) densities were calculated for the whole disc. This was done by recording the fresh green weights and volumes of the discs prior to drying to the oven-dry condition and re-weighing. Whole-stem average wood density was calculated from the individual disc values by weighting by volume.

Corewood was measured as the diameter of the first 10 growth rings from the pith and expressed as a percentage of the dub. This value gives the proportion of the low wood density and high spiral grain core.

Compression wood: The percentage of compression wood was obtained by visual estimation of the proportion of the disc affected.

The second disc from each sampling height was used for analysis of the following properties:

Spiral grain was measured for all heights on two diametrically-opposed sectors on every second growth ring. Latewood was exposed with a chisel, and grain direction was scribed with a " swinging arm grain scribe" (Harris 1989). Grain angle was measured in relation to the lower surface of the disc by a perspex protractor. The rings were numbered from the pith to the bark. Absolute values were used when calculating averages as it was the magnitude of the grain angle that was relevant in the context of this report, not grain direction.

Within-tree density trends: Radial samples were removed from all breast height discs for analysis in the NZ FRI Wood Densitometer (Cown & Clement 1983). Radial strips were resin-extracted in methanol in a Soxhlet extractor for 72 hours and then stored to equilibrate to 10% moisture content (mc) in constant 50% relative humidity.

The samples were then machined to 5 mm in height and 1.5 mm in width using a custom-designed twin-blade saw and re-conditioned to 10% mc at 50% relative humidity for several days prior to scanning. Density was measured by X-ray densitometry scanning strips at an interval of 0.3 mm (Cown & Clement 1983). The earlywood/latewood boundary was set at 400 kg/m^3.

Tracheid length was determined on the breast height strips at rings 2, 5, and 8 for the 11-year-old trial. Rings 2, 5, 10, 15, and 20, numbered from the pith, were sampled for the 25-year-old trees. The individual growth rings were macerated with hydrogen peroxide-acetic acid at 90°C for 4 to 5 hours. Fifty separated tracheids were measured by each of two operators, using a projected image and a measuring wheel linked to an electronic data recorder (Harris 1966).

Analyses of variance (ANOVA) were carried out to test the significance of the observed variations in properties between physiological ages. All tests were set a 5% level unless otherwise noted.

RESULTS AND DISCUSSION

Whole-tree Characteristics

Wood characteristics measured on the 11-year-old trees in the Kaingaroa and Tairua trials are given in Table 1. There were significant differences between physiological age levels at Kaingaroa for volume and percentage bark and at Tairua for heartwood. Standard errors indicate overlap between treatment means for several of the properties listed, which is expected for insignificant differences between treatments. There were no large differences or consistent trends apparent between the various types of plants represented in the trials.

TABLE 1–Whole tree characteristics (11-year-old Kaingaroa and Tairua trials)

Ageing (years)	Volume (m^3)		Basic density (kg/m^3)		Heartwood (%)		Moisture content (%)		Bark (%)		Compression wood (%)	
	Tairua	Kaing.	Tairua	Kaing.	Tairua	Kaing.	Tairua	Kaing.	Tairua	Kaing.	Tairua	Kaing.
Seedling	0.58	0.38b	349	341	5.8ab	3.1	190	214	6.4	8.4a	14.6	5.0
1	0.65	0.43a	350	329	5.2b	2.5	192	225	5.9	7.4ab	12.5	6.8
2	0.68	0.37b	348	336	4.8b	2.1	193	217	6.4	7.6ab	15.2	6.7
3	0.66	0.39abc	337	329	7.2a	3.6	200	216	6.0	8.1a	17.7	7.1
4	0.66	0.40ab	350	344	5.6ab	1.9	191	213	5.4	7.7a	12.8	7.4
5	0.58	0.35bc	363	333	4.1b	2.0	180	220	6.6	6.4b	13.1	3.7
Average	0.64a	0.39b	350a	335b	5.5a	2.5b	191b	218a	6.0b	7.6a	14.3a	6.1b
SE†	0.04	0.02	6.0	5.4	0.6	0.6	5.3	4.9	0.3	0.4	1.9	1.5
Sig.‡	ns	*	ns	ns	*	ns	ns	ns	ns	*	ns	ns

† Standard error of the mean.
‡ Significance of LSD test, 5% level (*)within trials, 1% level between trials.

Significant differences were found (1% level) between the Kaingaroa and Tairua sites for all the properties measured. Trees at the Tairua trial had significantly higher volume, density, heartwood, and compression wood had a significantly lower moisture content and percentage bark.

The average basic density at Tairua (350 kg/m^3) closely matched that expected for northern sites (e.g., Tairua, Rotoehu, and Tarawera Forests) for 10-year-old trees (Cown *et al.* 1984). Similarly, the average basic density at Kaingaroa (320 kg/m^3)was close to the expected. Moisture contents were also close to the expected level—the Kaingaroa predicted moisture content was 200% and averaged 218%. Tairua predicted moisture content was 175% and averaged 191%.

The heartwood (3%) for Kaingaroa was as expected (2%). The heartwood for Tairua was 5% but only 2% was expected.

In the 25-year-old trial at Kaingaroa seedlings had significantly (1% level) thicker bark than cuttings (Table 2),but bark percentage was significant only for the lower 6.4 m of tree.

TABLE 2–Wood properties (whole tree) for the 25-year-old Kaingaroa trial

Physiological age (years)	Volume (m^3)	Density (kg/m^3)	Heartwood (%)	Moisture content (%)	Bark (%)	Compression wood (%)	Corewood (%)
0 (seedlings)	2.53	405	19.0	142	6.3	8.3	67
12–16 (cuttings)	2.40	386	22.8	143	4.3	10.0	68
Average	2.46	396	20.9	143	5.3	9.1	67
SE†	1.99	2.0	1.7	3.8	0.2	1.5	1.1
Significance‡	ns	*	ns	ns	**	ns	ns

† Standard error of the mean.
‡ LSD test, 5% level (*) or 1% level (**)

Cuttings had a significantly (5% level) lower density than seedlings by about 20 kg/m^3, but density differences were significant only in the lower 6.4 m of tree. There were no significant differences between seedlings and cuttings for the other properties which have corresponding standard errors that overlap treatment means.

Density and moisture content were close to those predicted by Cown *et al.* (1984). Predicted density for sawlogs was 415 kg/m^3 and for toplogs was 385 kg/m^3 and the trial tree density was 396 kg/m^3. The expected moisture content for sawlogs was 135% and for toplogs 165%, and the trial whole-tree moisture content was 143%.

The density of the 5-mm outerwood cores that were taken from all the trees had a correlation of 0.84 with whole-tree density, once again showing agreement with predicted values (Cown *et al.* 1984).

Within-tree Trends

Spiral grain

There was large between-tree variation in spiral grain within each age level, including variation in direction of the spiral grain (left- and right-hand spiral).

At Kaingaroa there was a slight trend for higher grain angles in cuttings (Fig. 1), although the only significant difference between stock types was in ring 10 in the butt disc. There was no apparent trend with physiological age since the 5-year-old cuttings had spiral grain angles between those of seedlings and 1-year-old cuttings.

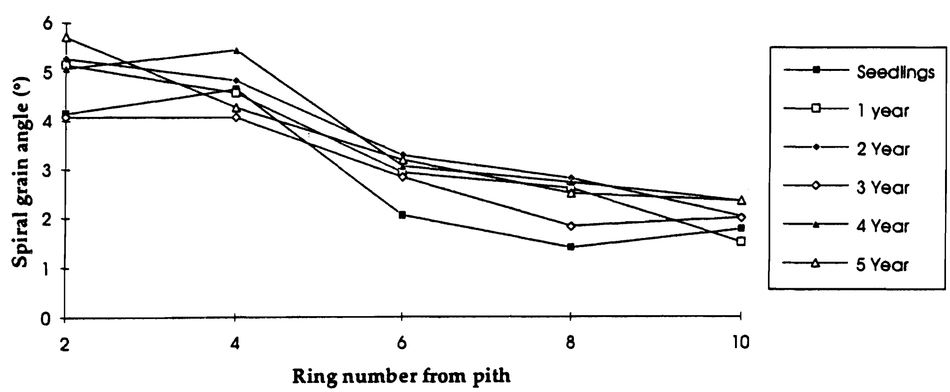

FIG. 1–Absolute spiral grain angles at breast height (11-year-old trees at Kaingaroa).

At Tairua five rings showed statistically significant differences between the ages (rings 2 and 6 in the 1.4-m disc (Fig. 2); rings 2, 4, and 6 in the 6.4-m disc). Again there was no consistent trend with spiral grain with changing ageing level. The other sample heights for both sites showed an increase in grain angle with sample height and similar radial trends.

In Fig. 3 the spiral grain data from both Kaingaroa and Tairua have been summarised by averaging all observations in all heights for each ring.

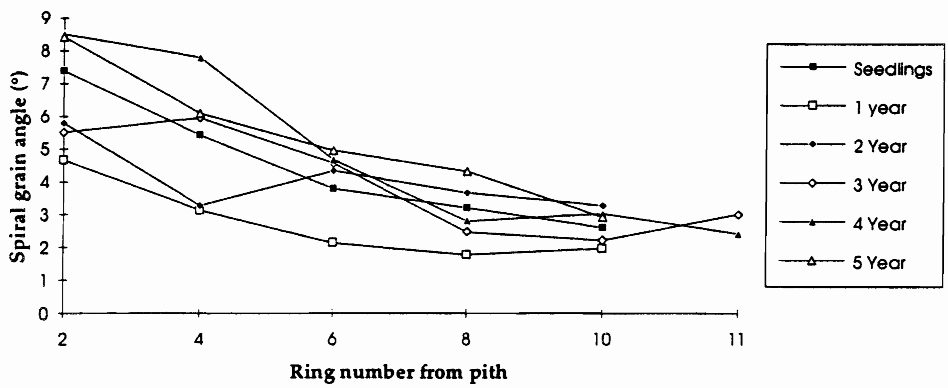

FIG. 2–Absolute spiral grain angles at breast height (11-year-old trees at Tairua).

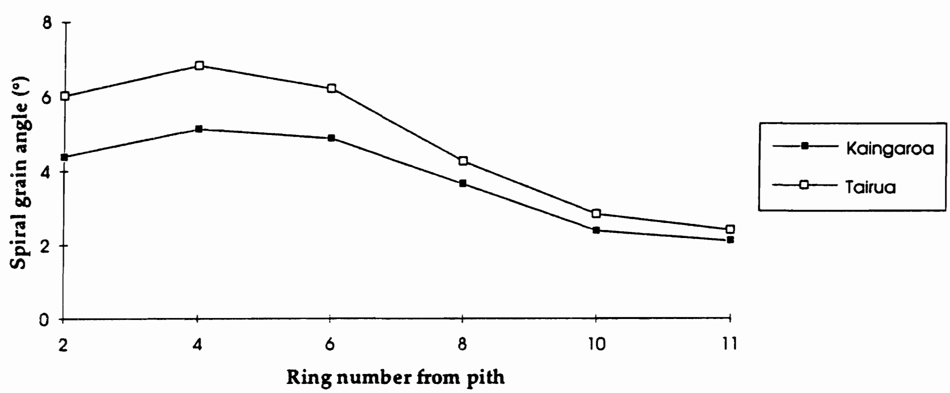

FIG. 3–Average whole-tree radial spiral grain pattern in 11-year-old trees at both sites.

There was a large difference between the two sites in terms of average spiral grain angles. Tairua had a higher average spiral grain angle for all radial positions. The angles were significantly greater (0.1% level) in rings 2, 4, and 6 and less so (5% level) in ring 8. The differences between sites in rings 10 and 11 were not significant.

In the 25-year-old stand, both seedlings and cuttings had similar spiral grain angles near the pith (Fig. 4 and 5). For the cuttings the angles increased in the first 4–6 rings, while for the seedlings they steadily decreased. The cuttings had significantly higher (5% level) spiral grain angles in rings 4, 6, and 8.

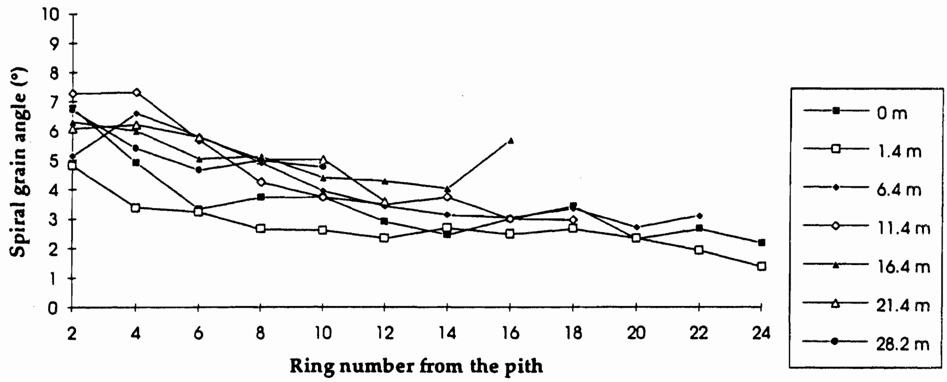

FIG. 4–Average spiral grain pattern for the seedlings (25-year-old trees at Kaingaroa).

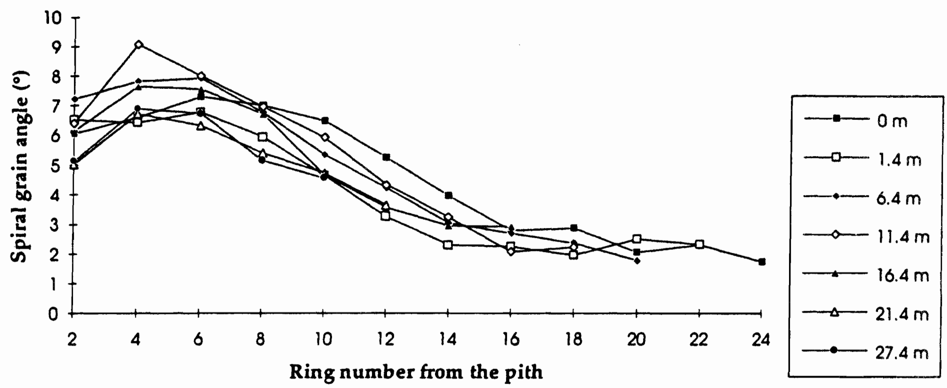

FIG. 5–Average spiral grain pattern for the cuttings (25-year-old trees at Kaingaroa).

Tracheid length

There were no significant differences in tracheid length between any of the ages in the trials of 11-year-old trees at Kaingaroa and Tairua (Fig. 6 and 7). No significant differences were observed between the two trial sites for tracheid length in ring 2. The Kaingaroa trial had significantly longer tracheids in ring 5 and significantly shorter tracheids in ring 8.

Tracheid length was measured on breast height samples at rings 2, 5, 10, 15, and 20 for the 25-year-old material at Kaingaroa (Fig. 8). Cuttings had significantly longer tracheids only at ring 2 (0.6 mm, 0.1% level) and ring 5 (0.5 mm, 5% level). There was no significant difference between the cuttings and the seedlings for any of the other rings.

Wood density patterns

In the 11-year-old material at Kaingaroa and Tairua, the only significant difference in mean ring density between physiological ages was in ring 9 at Tairua; however, this didn't match the age trend (Fig. 9 and 10). Average density for all ages was higher at the Tairua site than at Kaingaroa (Fig. 11), which conforms to the expectations of Cown *et al.* (1984).

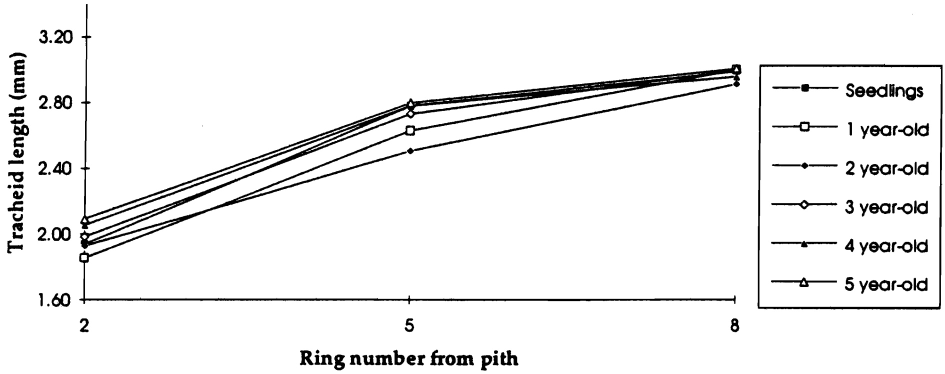

FIG. 6–Tracheid length by ring number (11-year-old trees at Kaingaroa).

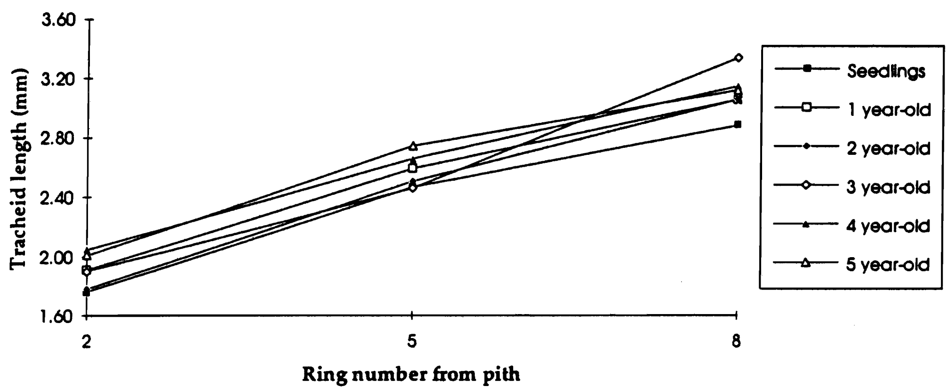

FIG. 7–Tracheid length by ring number (11-year-old trees at Tairua).

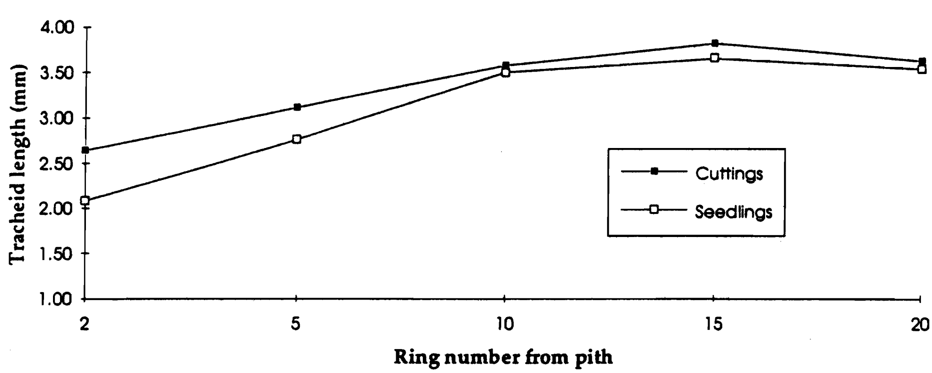

FIG. 8–Average tracheid lengths for the seedlings and cuttings (25-year-old trees at Kaingaroa).

There was no significant difference between the mean densities in rings 1 and 2. The Tairua mean ring densities were significantly higher (1% level) in ring 3 and for rings 4 to 9 (0.1% level). These higher density values for the Tairua site were explained by significantly

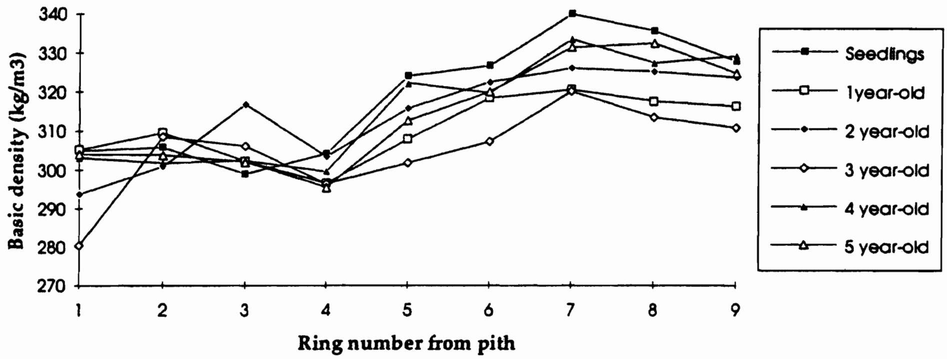

FIG. 9–Radial mean density trends for all treatment ages, measured by X-ray densitometry (11-year-old trees at Kaingaroa).

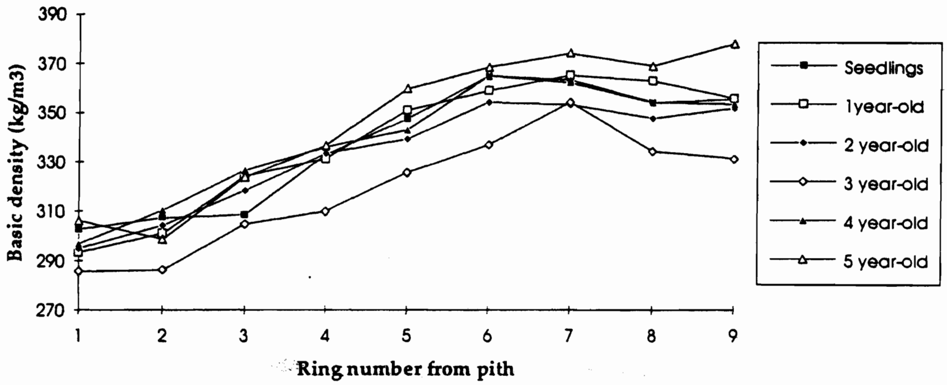

FIG. 10–Radial mean density trends for all treatment ages, measured by X-ray densitometry (11-year-old trees at Tairua).

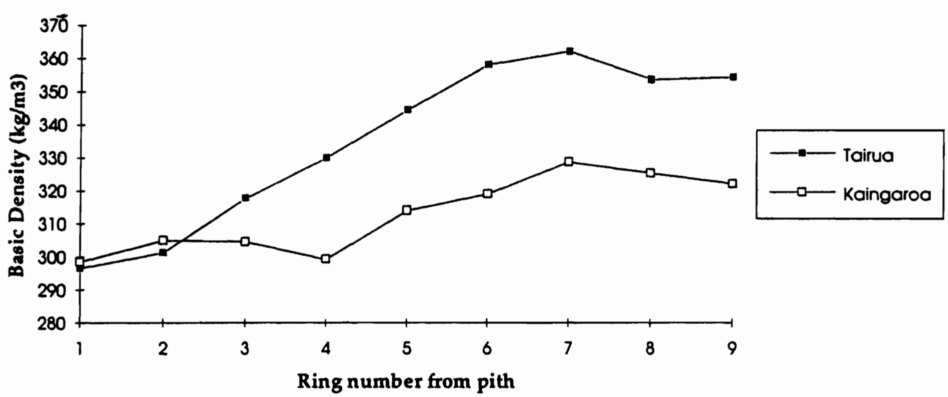

FIG. 11–Average radial mean density trends for 11-year-old trees at both sites.

higher (1% level) earlywood density (307 *v*. 290 kg/m^3) and latewood percentage (17.8 *v*. 12.5%). There were no significant differences in average latewood density.

In the 25-year-old material, cuttings had consistently lower density than seedlings although the shape of the pith-to-bark pattern was similar (Fig. 12). The cuttings were consistently significantly lower (30–40 kg/m^3, 5% level or better) in rings 1, 5, 6, 9, 10, 12, 14, 16, and 20–22. Overall these differences were due to the seedlings having significantly higher (0.1% level) earlywood density (328 *v.* 315 kg/m^3) and latewood percentage (36.8 *v.* 26.1%).

There was no significant difference in latewood density between the cuttings and the seedlings.

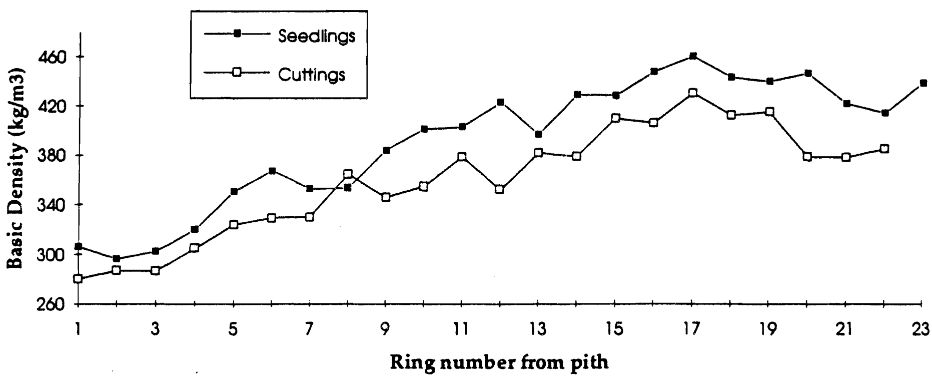

FIG. 12–Radial mean density trends for the seedlings and cuttings of the 25-year-old trial.

CONCLUSIONS

Cown (1988) concluded that physiological ageing of 7 years or less in cuttings will produce wood properties similar to those of seedlings. That was supported in this study since there were few significant differences and no consistent trends with increasing physiological ages in the 11-year-old material (aged 1-5 years). Sample size may have been too small to detect significant trends, the trials may have been too young, or physiological ageing of 5 years may not significantly affect wood properties. However, trial age is probably not important as densitometric analyses of the older (25-year) trees indicated consistent density differences from pith to bark associated with a greater degree of physiological ageing.

Physiological ageing of up to 5 years had little or no impact on wood characteristics. This contrasts with the 25-year-old cuttings (physiologically aged 12–16 years) which had significantly lower density, higher bark percentage, shorter tracheids in rings 2 and 5, and higher spiral grain angles in the first 14 rings than the seedlings.

It seems that the use of aged vegetative propagules for their genetic gain, good form, and branching characteristics does not involve a trade-off in growth or density if the parent material is 5 years old or less. Current clonal forestry strategies of using 3- to 5-year-old trees to produce the planting stock by vegetative propagation (Menzies *et al.* 1991) should not cause apparent changes in the major wood properties considered here.

As expected, site had a significant effect on all wood properties, including spiral grain and densitometric characteristics. Trees at Tairua had significantly higher stem volume, average basic density, earlywood density, latewood percentage, heartwood percentage, compression wood, and spiral grain while trees at the Kaingaroa site had significantly higher moisture content and bark percentage. Site effects on wood properties far outweighed the effects of using cuttings obtained from up to 5-year-old trees.

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