WOOD PROPERTIES OF *PINUS RADIATA*: SEED-GROWN TREES COMPARED WITH GRAFTS FROM DIFFERENT-AGED ORTETS

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ABSTRACT

Wood properties of trees grown from seed are compared with those of grafts made from ortets aged 6, 15 and 40 years. With the change from seedling to mature state, diameter growth, bark thickness, wood density and shrinkage decreased in value, while tracheid length, extractives content and pith diameter increased in value. Marked clonal variation, which was independent of maturation state, occurred in many of the characters examined, making it desirable that wood properties be incorporated in clonal selection programmes.

INTRODUCTION

It is now technically possible to establish plantations of *Pinus radiata* D. Don with rooted cuttings (Thulin and Faulds, 1968), and this procedure offers some advantages over establishment with seedlings. These have been summarised by Libby *et al.* (1972) as:

(i) reduction of the defects associated with the juvenile habit,

(ii) increased genetic gain from selection,

(iii) improved uniformity of crop, and

(iv) more rapid build-up of genetically improved material.

There are also, however, disadvantages associated with the fact that following selection, testing, and multiplication cuttings have of necessity some degree of physiological maturity. Sweet (1973) and Sweet and Wells (1974) have shown that cuttings of *P. radiata* have lower rates of diameter and stem volume growth than seedlings, and that cuttings from older ortets have significantly lower rates of diameter growth than cuttings from younger ortets. Tufuor and Libby (1973), using 11-year-old ortets, have confirmed the comparison with seedlings.

Clearly, if rooted cuttings are to be seriously considered for afforestation their wood properties should be at least as good as those of seedlings. Yet there is some doubt

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that this is so in *P. radiata.* In Australia, Nicholls and Brown (1971) compared wood properties of selected plantation-grown trees (ortets) with those of rooted cuttings and grafts (ramets) established from the ortets when they were aged between 20 and 30 years. On average, ramets of both types had longer tracheids, but greater spiral grain and less dense wood than did comparable growth rings in the ortets. However, the growth rings examined were, of course, formed in different years and under different seasonal conditions. The ortets and ramets were also located at a considerable distance from one another. In a subsequent experiment (Nicholls *et al.,* 1974) these deficienices were remedied: ortets (one series aged 14 years, and a second series 33 years) were propagated both sexually and asexually and the seedling and vegetative propagules were planted in the same year on the same sites. This experiment generally confirmed the first, showing grafts to have lower average density and less latewood than seedlings, but longer tracheids. The situation with spiral grain was not so clear-cut as in the first experiment, but generally followed the same trend. In California, Tufuor *et al.* (in prep.) compared cuttings from 5-year-old trees with seedlings. They found little difference between the groups in corewood specific gravity, spiral grain or tracheid length, and thus believe that in terms of wood properties plantations of cuttings can be safely established with material raised from young ortets.

In the trial reported here, the wood properties of grafts from parent ortets of varying ages were compared with those of seedlings. The material has advantages over that used by Nicholls *et al.* (1974) and Tufuor *et al.,* in that it covered a range of ortet ages in the one experiment and thus throws some light on patterns of change in wood properties accompanying the change from the juvenile to the mature state. Although examination was made of grafted material it is clear from the work of Nicholls and Brown (1971) that the wood properties of cuttings and grafts from the one clone are essentially the same. The results of the experiment are therefore relevant to consideration of plantation establishment with cuttings.

MATERIAL

The wood samples came from a trial established at Kaingaroa to compare the growth of grafts and cuttings from different-aged ortets. It has been described in detail by Sweet (1973). The grafts came from ortets which were aged 6, 15, 25, 43 and 66 years, respectively, at the time the trial was planted (1968). They were designated G6, G15, G25, G43 and G66, respectively. Each ortet age was represented in the trial by five clones with nine ramets per clone. The grafts were planted at a spacing of 5.5 × 5.5 m and were interspersed with seedling fillers (aged two years from sowing when the trial was planted and designated S2) to an overall spacing of 2.7 × 2.7 m. At the time when the wood samples were taken a thinning had increased the spacing to 2.7 × 5.5 m. Sampling took place in 1974 when all grafts were felled.

Wood properties were examined from grafts of only three ortet ages (G6, G15, and G43), and were compared with those of seedlings (S2). Previous studies (Sweet, 1973) have shown that phase change (the change from the juvenile to mature state) was complete in *P. radiata* by age 20, and no differences have been shown between propagules from ortets aged 43 and 66 in either growth or form.

METHODS

The wood properties examined are listed in Table 1. Generally, all five clones of each ortet age-class and the nine ramets per clone were sampled (where these had survived and did not show signs of graft incompatibility — *see* Sweet & Wells, 1974). However for tracheid length, extractives content and values obtained by β-ray densitometry, sampling was three clones in each ortet age-class with five ramets per clone. Compression wood was excluded from all samples used for measuring other wood properties. One seedling was sampled for each grafted ramet in an ortet age-class and thus the mean value for the seedling has the same numerical basis as that for other groups.

The statistical significance of differences between seedlings and grafts was examined by t-test. To meet the requirements of this test, clonal mean values were tested against individual seedling values. To examine differences between ortet age classes within the grafts, the following analysis of variance was used:

	d.f.
Between ortet age-classes	2
Between clones within ortet ages	12
Residual	113
Total	127

The degrees of freedom for the reduced sample used for tracheid length, extractives content and β-ray densitometry were 2, 6, 36 and 44 respectively, and for the wood density analyses a further partitioning into growth rings within ramets, clones, and ages was carried out.

Details of specific assessment methods are as follows:

Average wood density (oven dry weight/green volume) was determined by conventional gravimetric methods, using water displacement to measure volumes. Wood samples were diametrically opposed sectors, cut from cross-sectional discs containing four annual growth layers. In this way the values obtained are automatically "weighted" in proportion to the volumes of the component growth increments in a transverse stem section.

β-ray densitometry. Methods were those described by Harris (1969). Radial wood sections were cut from trees sampled as described. The clones were selected to represent, as far as possible, the complete range of density values encountered and at the same time to approximate the average value for each ortet age-class. From the densitometer record for each annual growth layer were obtained mean density, minimum density, and maximum density (all measured at 10% moisture content), and latewood ratio. Latewood ratio, a term used by Harris (1969) and Nicholls and Brown (1971), describes latewood development in terms of density variation within an annual growth layer, and is numerically equal to:
(mean density — minimum density) ÷ (maximum density — minimum density).

Shrinkage. Volumetric shrinkage was derived from stem sector volumes measured in determining average wood density, and dimensional shrinkages from measurements made between marked points on the same wood samples.

TABLE 1—Wood properties of seedling and grafted trees

	Diameter inside bark (mm)	Bark thickness (mm)	Pith diameter (mm)	Mean growth rate (mm/ring)	Density in Growth Rings 1-4 (kg/m³): Average basic density	Density: Within-ring density at 10% M.C.: Mean	Min	Max	Tracheid Length (mm): Growth ring 2	5	Compression wood (%)	Mean grain angle (Rings 2-5) (°)	Shrinkage to Air Dry (%): Longitudinal	Tangential	Radial	Volumetric	% of extractives
S2	165	6.2	3.7	15.8	332	422	351	580	1.73	2.40	10.3	5.8	0.05	3.73	1.88	6.51	2.9
G6	160	5.2	4.5	15.2	345	406	325	603	2.15	2.66	19.6	3.8	0.36	3.46	1.68	6.02	3.0
G15	135	4.1	5.6	12.7	326	373	303	544	2.41	3.06	13.5	7.6	0.19	3.08	1.45	5.78	3.7
G43	127	4.6	5.1	11.9	313	370	297	547	2.47	3.11	12.4	5.2	0.16	2.41	1.37	4.86	4.1
G43 as % S2	77	74	138	75	94	88	85	94	143	130	120	90	320	65	73	75	14.1
Significance of t-test																	
$\bar{S}2$ v $\bar{G}$ (%)	1.0	0.1	0.1	0.1	N.S.	0.1	0.1	N.S.	0.1†	0.1	5.0†	N.S.	0.1†	0.1	0.1	0.1	N.S.
Percent distribution of total variation in grafts																	
Between ortet age-classes	22.1*	27.8**	10.9*	21.9*	10.0	9.2	0	8.5	33.4	34.2	5.6	22.6	37.9**	40.0**	9.8	37.4*	25.5**
Between clones within ortet age-classes	34.6	11.5	0	33.6	65.0	54.5	64.2	25.9	45.3	45.1	14.8	63.4	17.7	33.4	58.8	34.7	12.5
Between ramets within clones	43.3	60.7	89.1	44.5	25.0	4.7	2.6	0	21.3	20.7	79.6	14.0	44.4	26.6	31.4	27.9	62.0
Between growth rings within ramets						31.6	33.2	65.6									

* = significant at 5%

** = significant at 1%

† = difference between $\bar{S}2$ and $\bar{G}6$ is also significant by t-test

Tracheid length was obtained from each annual growth layer using a projection microscope and following the method of Harris (1966).

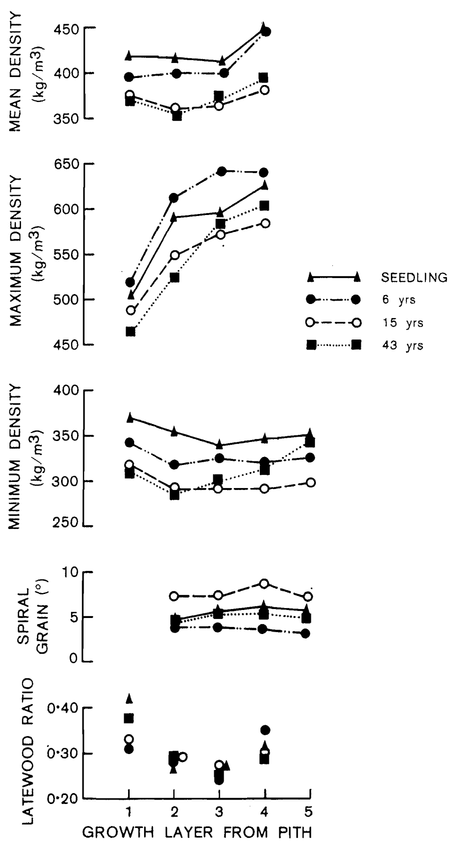
Extractives content was obtained by 24-h Soxhlet extraction using methanol as the solvent. Narrow stem sectors were ground to pass 100-mesh in a Wylie mill. Extractives loss was recorded by weighing before and after extraction.

Compression wood was estimated visually by two independent observers. Various proportions of compression wood were drawn on squared paper to represent increasing intensity (0-5% of the total cross sectional area, 6-10%, 10-15%, and so on), and by comparing discs with these, percentage of compression wood was allocated to the appropriate grouping.

RESULTS

These are summarised in Table 1 and Fig. 1. Most of the wood properties either increased or decreased from seedling to grafts of increasing ortet age. Most of the differences between the mean values for seedlings and grafts were highly significant, but with the limited degrees of freedom available, only three of the wood properties could be shown to differ significantly between seedlings and the G6 grafts.

FIG. 1. Radial variation in wood properties for trees grown from seed and for grafts of different ortet ages.



Essentially, seedlings had significantly higher mean values than the grafts for diameter and growth rate, bark thickness, within-ring wood density, and shrinkage on air drying; and all these parameters decreased with increasing ortet-age of graft. In contrast to this, seedlings had significantly lower values than grafts for tracheid length and pith diameter, and these differences largely increased with increasing ortet age. For a number of wood properties it was not possible to show statistically significant differences between ortet ages of the grafts. This was in part due to the extent of the variability between clones within ortet ages. This is illustrated in Table 1 by the distribution of the total variation for each wood property, calculated from variance components. The variation between clones within ortet ages was particularly high for density, tracheid length, and grain angle. It was lowest for properties such as pith diameter, bark thickness, and percentage of extractives.

DISCUSSION

This trial shows that major trends in wood properties with tree development are similar to those already published. That is, with change from the juvenile to mature state, diameter growth is decreased, as are mean and minimum wood density, and tracheid length is increased.

Variation between clones within ortet age-classes has been referred to already. This was particularly marked in the wood density of the clones derived from ortets aged six years where average basic density varied from 285-369 kg/m^3. In selection of three clones for densitometry, inclusion of the one with lowest wood density has obviously had the effect of depressing mean densitometer values for this ortet age-class relative to that for seedlings (Table 1). However, the variation in average wood density indicated by the densitometric parameters in each growth layer (see Fig. 1) remains, and does differ in some respects from that presented by Nicholls *et al.* (1974). In the present study, latewood ratio cannot be shown to make a significant contribution to density differences between ortet age-classes. These arise primarily from differences (presumably related to cell-wall thickness) across the entire annual growth layer, so that both minimum (earlywood) and maximum (latewood) values are reduced with increasing ortet age. Only in the clones selected within the six-year age-class do high maximum densities compensate for low minimum densities when compared with trees grown from seedlings.

It is this issue of reduced wood density that has most concerned protagonists of plantation establishment with cuttings (apart from the loss in diameter and volume growth which has been well discussed elsewhere). Tufuor *et al.* show that this reduction in density between seedlings and young cuttings is far less than that between seedlings and older cuttings (as shown by Nicholls *et al.*). Our study confirms that point, illustrating for the first time that changes in wood properties from the juvenile to the mature are progressive—as are those of other physiological and morphological aspects examined.

Because of the need to maintain growth rates as close as possible to those of seedlings it is certain that plantations from cuttings will be established with ramets which are physiologically as juvenile as procedures for selection, testing, and build-up of material will allow. This will depend in part on how effective hedging (Libby *et al.*,

1972) proves to be in maintaining juvenility; a point on which there is at present little documented evidence. But this trial suggests too that much of the difference in wood density between cuttings and seedlings can be eliminated if clonal selection is made to include high density wood.

Overall, if careful clonal selection takes wood properties into account, and if efforts are made to obtain and maintain clonal material as juvenile as possible, this trial demonstrates no reason to reject plantations of *P. radiata* cuttings on the basis of wood properties. Indeed, it seems that cuttings from juvenile material could have a special place in establishment of plantations for specific end-uses, taking advantage of the high heritability for wood density. The economics of such special plantations are currently attracting considerable interest, as is illustrated by the use of *P. radiata* for post and pole production.

Clonal material has the immediate advantages of higher form factor and smaller butt swelling (Sweet, 1973), and thinner bark. Because poles should contain at least 15 growth layers in the small end (Walford and Hellawell, 1972), growth in diameter will have to be restricted by close spacing. Thus any natural reduction in diameter increment of clonal material would be no disadvantage. Wood density, particularly of the outer 2 cm of wood, is very important in determining pole strength (Hellawell, 1965), and young trees in which wood density had been accorded high priority for selection could provide the best possible source material.

Slope of grain at the pole surface is required not to exceed 1 : 10. In a previous study of clonal *P. radiata* (Harris, 1965) there was very little difference in the *magnitude* of spiral grain angle between clones, though the *pattern* of spiral grain development seemed to be more uniform within clones than between clones. However, in the present study there were different levels of spirality between clones (Table 1). In the 15-year ortet age-class average grain angles in the outer growth layer of three of the clones were more than 10°, and for the other two clones less than 3°.

Finally, some reference should be made to the apparent influence of phase change on pith diameter. The normal increase of pith diameter from the base of a tree for some distance up the stem and its subsequent reduction towards the top is usually regarded as being related to the vigour of the leading shoot at the time the pith was formed—pith being regarded as the "residual" undifferentiated cells inside the primary xylem. In this study, clones of increasing ortet age-class have significantly larger pith despite the fact that diameter increments are significantly smaller. It can only be assumed that the effect of maturation on pith diameter is stronger than any influence of growth rate.

Selection and testing of ramets, so long as these are derived from juvenile trees prior to completion of the phase change, therefore holds promise of providing control over a number of important wood properties.

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