PERFORMANCE OF PINUS RADIATA SEEDLINGS AND CUTTINGS TO AGE 15 YEARS

B. K. KLOMP and S. O. HONG
Forest Research Institute, New Zealand Forest Service,
Private Bag, Rotorua, New Zealand

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ABSTRACT

In a 2-ha block of alternate rows of seedlings and cuttings of **Pinus radiata** D. Don established on a cleared indigenous forest site, mortality during the first 6 years after planting was higher among cuttings from 7-year-old trees (37%) than among seedlings (22%). There were more deaths associated with Armillaria root rot among cuttings (23%) than seedlings (13.5%) over the same period. No significant difference in height growth was evident between the two types. Although cuttings were smaller in diameter at breast height (a difference of 1.8 cm at plantation age 6 years and 2.6 cm at 15 years), annual diameter increments during the period 12–15 years after planting were not significantly different. Cuttings had fewer culls as they had less malformation and a more uniform size. Although cuttings had fewer branches in the low pruning zone, seedlings had fewer branches in the high pruning zone, and the pruned butt log over-all (0–6 m) contained an equal number of branches and branch whorls for both seedlings and cuttings. Seedlings had a significantly larger mean branch basal area. Seedlings took longer to prune (10.2 min/tree) than cuttings (7.7 min/tree) and in all three pruning lifts had larger diameters over stubs (17, 21, and 24 cm) than cuttings (15, 18, and 21 cm) because of their larger diameters at breast height.

Rooted cuttings appear to have some silvicultural advantages over seedlings, such as lower stockings required at planting because of less malformation, smaller branch size, shorter pruning times, and greater uniformity of size.

Keywords: Pinus radiata; rooted cuttings; seedlings; pruning.

INTRODUCTION

Afforestation using rooted cuttings from selected parent trees makes it possible to establish forests with greater uniformity of tree size, log quality, and wood properties (Fielding 1964; Wilcox *et al.* 1976; Zobel & Talbert 1984). However, its practical application has been limited to only a few easy-to-root species – for example, in the genera *Populus, Salix, Cryptomeria,* and *Chamaecyparis*. As the techniques of vegetative propagation have been further developed, establishment of plantations from cheaply mass-produced rooted cuttings has become economically feasible in an increased number of timber genera which are relatively difficult-to-root including *Pinus, Picea,* and *Eucalyptus* (Fielding 1964; Thulin & Faulds 1968; Libby *et al.* 1972; Kleinschmit *et al.* 1973; Campinhos & Ikemori 1983). As a result foresters in many parts of the world have become interested in the direct use of rooted cuttings for operational production forestry.

In New Zealand, experience with growing *Pinus radiata* from cuttings dates back at least 50 years (Field 1934), but until recently only small trial-plantings have been made.

Results of field research comparing *P. radiata* seedlings with cuttings carried out in Australia, New Zealand, and California during the past 20 years have been summarised by Bolstad & Libby (1982). The merits of growing *P. radiata* cuttings rather than seedlings have been reported by Fielding (1964, 1970), Thulin & Faulds (1968), Pawsey (1971), Libby *et al.* (1972), Shelbourne & Thulin (1974), and Wilcox *et al.* (1976). Generally, height growth of seedlings exceeds that of cuttings (ortet age range 5–15 years) for the first three growing seasons. However, subsequent height growth seems to be equal and cuttings may eventually even outgrow seedlings. In contrast, diameter growth during the first 8–10 growing seasons is strongly and negatively related to the maturation state of the propagule, with seedlings having better diameter growth than cuttings from mature ortets (Fielding 1970; Sweet & Wells 1974; West 1984). Seedlings have thicker bark, are more tapered, and have a greater tendency to sweep, crook, and fork than cuttings from older ortets. Vegetative propagules from more mature ortets generally have better bole form than do those from juvenile ortets (Fielding 1970; Bolstad & Libby 1982). Ramets from adolescent or mature ortets develop fewer, shorter, and smaller-diameter primary branches on the lower bole than those from juvenile ortets and these occur at a more perpendicular angle. These latter characteristics generally result in faster pruning times as well as fewer knot-related defects (Tufuor & Libby 1973).

Silvicultural treatment, mainly thinning and pruning, has been an integral part of much of the *P. radiata* plantation management in New Zealand. The "direct sawlog regime" advocated by Fenton *et al.* (1972), incorporating early thinnings and prunings, is now widely implemented, sometimes with minor adjustments to suit local conditions. However, despite the apparent merits of cuttings for use in this type of regime, the result of only one small pruning trial comparing cuttings with seedlings has been published (Tufuor & Libby 1973). In a comparison of seedlings with rooted cuttings in a low pruning lift (to 1.5 m), they found that the pruning times for cuttings were consistently and significantly less than for seedlings. Pruning of cuttings and grafts averaged 1.50 min/per tree, but pruning of seedlings averaged 2.52 min/per tree.

In general, there is little information available comparing the characteristics and performance of cuttings and seedlings under an intensive pruning and thinning regime (Zobel & Talbert 1984).

The study reported here compared seedlings and cuttings of *P. radiata* for 15 years with respect to:

(1) How well they could be established on a site cleared of indigenous forest where Armillaria root rot was present;

(2) What differences there were in long-term growth performance;

(3) Whether there were differences in silvicultural parameters such as branch characteristics, diameter over stubs, and pruning time at different pruning lifts.

MATERIALS AND METHODS

Locality and Site Description

The trial area was located on the Mamaku plateau (lat. 38° 2′ S, long. 176° 1′ E) at an altitude of 550 m. It was one of the first row by row comparisons of *P. radiata* cuttings and seedlings planted on a cutover indigenous forest site. The original podocarp/hardwood forest was first logged about 1952 and the reverted cutover forest was crushed by crawler tractor with some large residual trees felled prior to burning in 1969. The terrain was flat to slightly undulating. The soils consisted of about 15 cm of friable sandy loam over a reddish brown silty loam (Mamaku ash, $\geq$ 15 cm) and a yellow silty loam (Rotorua ash, $\geq$15 cm) overlying sheets of ignimbrite. An important feature of the soils over most of the Mamaku plateau is the high allophane content in the Mamaku and Rotorua ash layers, making the soil very greasy and easily compacted. The combination of a cool wet climate (annual rainfall 2000 mm) and soils with these characteristics seems to result in rather slow early growth of *P. radiata.*

Planting Stock

Both seedlings and cuttings were of "bulk collected" (non-seed-orchard) origin. The seedlings were 1.5/0 nursery stock raised from seed collected in 1968 from Cpt 833 of Kaingaroa State Forest and the cuttings were 0/1 bulk-collected from 7-year-old trees (a 6-year-old plantation) in 1969 from Cpt 121, Kaingaroa Forest. Both types of planting stock were raised in the Forest Research Institute nursery at Rotorua.

Planting Layout

The 2-ha block was planted by hand in August 1970 with cuttings and seedlings in alternate rows, 3.6 m apart. Trees were planted 1.8 m apart within rows, giving a nominal stocking of 1540 stems/ha. Due to obstructions such as unburned or buried slash and stumps, the actual stocking achieved was 1420 stems/ha, or 92% of the nominated stocking.

Data Collection

The growth data presented are based on three different sets of plots within the trial area. Height growth and survival during the first 4 years were assessed in 10 randomly distributed transects throughout the block. Each transect consisted of two adjacent rows of 10 cuttings and 10 seedlings.

At plantation age 6 years, after a first thinning to approximately 500 stems/ha and immediately prior to the first pruning lift, a new arrangement of plots was necessary to assess morphological differences between cuttings and seedlings during the silvicultural treatment period (age 6–10). Fifty individual pairs of trees with matching heights and similar dominance status were chosen throughout the block. All growth data relating to the 1976–80 period were obtained from this paired arrangement but mortality assessment was based on all trees in the trial.

After two more thinnings and further attrition of the crop element by mortality and wind damage, the final 4 years of diameter growth and mortality data were based on all trees left in the trial, that is 155 seedlings and 195 cuttings in 18 row-pairs. Height growth data for this period were based on a sample of 40 trees of each type.

Crop selection and malformation assessments were based on all trees in the block.

All annual growth assessments were carried out in the winter period when *P. radiata* growth rate is at its slowest.

The three pruning lifts were also done during the winter months. The low lift was carried out at plantation age 6 years, to a nominal 40% tree height at mean crop height 6 m. The medium lift to 4 m and high lift to 6 m were done at mean crop height 9.1 m (age 8) and 12.4 m (age 10), respectively.

Diameter measurements of all branches to be pruned were taken before each pruning lift. These were taken in the horizontal plane about 2 cm out from the trunk, to enable correct placement of the calipers.

Pruning times recorded are actual and for the medium and high lifts the ascent and descent on the ladder are included but the "walk and select" element between trees is not. The low lift was done using Porter pruners with a jacksaw (carried in a holster) as an optional tool when needed for occasional big branches. The medium and high lifts were done using ladders and jacksaws.

In order to compare seedlings with cuttings the data were statistically analysed by paired t-tests, except the data for height growth 12–15 years for which a non-paired t-test was used. Correlation and regression analyses were done to determine relationships between pruning time, basal area of pruned branches, diameter at breast height, and diameter over pruned stubs.

RESULTS

Mortality

Survival of the seedlings and cuttings was 77.8% and 62.6% respectively (significantly different at $p = 0.01$) 6 years after planting and before the first thinning and pruning operations were carried out. A major cause of the early mortality was Armillaria root rot. Deaths associated with the fungal infection were 13.5% for seedlings and 23% for cuttings (significantly different at $p = 0.01$) (Fig. 1). Mortality peaked within the first 5 years after planting with a mere 1.3% of seedlings and 1.2% of cuttings succumbing during the period 6–15 years. Mortality up to stand age 15 years was 23.5% for the seedlings and 38.6% for the cuttings.

Height Growth

The height growth pattern for the first 15 years is shown in Fig. 2. The seedlings (45 cm) were significantly taller at planting than the cuttings (35 cm) ($p = 0.01$) but, after adjustment for initial height differences by covariance analysis, height growth for seedlings and cuttings was not significantly different for the first 4 years. The 6–10 year growth data were based on the pairs initially matched for equal height, but again no significant difference in height growth occurred through to age 12. The last 4 years of measurement include a PMH (predominant mean height) value to enable comparison with other forest stands. No significant difference in PMH was found between the two types.

Diameter Growth

Measurement of the diameter at breast height over bark (d.b.h.) commenced at the low pruning operation at plantation age 6 years. At this time cuttings were sig-

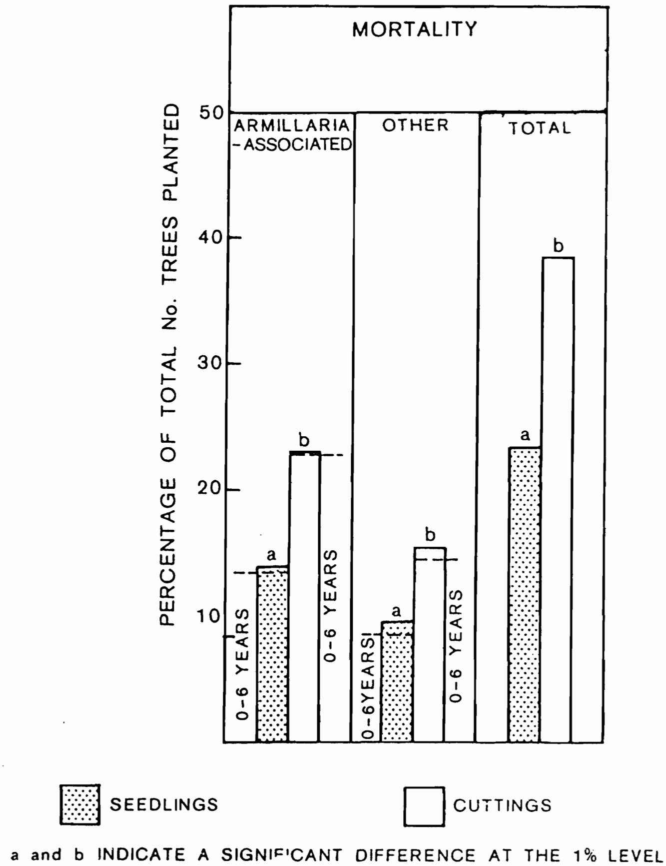

FIG. 1—Mortality in the first 6 years after planting.

nificantly smaller in diameter (10.6 cm) than seedlings (12.4 cm). This initial deficit of 1.8 cm had increased to 2.6 cm at the time of the final assessment at age 15 when cutting d.b.h. was 34.5 cm and seedling d.b.h. was 37.1 cm (Fig. 3).

Diameter increment, although not significantly different in the first year after pruning, became progressively less for cuttings than for seedlings through the remainder of the pruning period (significant at $p = 0.01$). After further thinnings down to a virtual final-crop stocking of 250 stems/ha at age 12, the diameter increment for the following 3 years was not significantly different although the difference in mean d.b.h. remained.

Crop Selection and Malformation

The silvicultural regime used in this study was based on the direct sawlog regime. The pruning lifts were accompanied by thinnings and a further thinning was done at age 12, resulting in a final crop of 250 stems/ha.

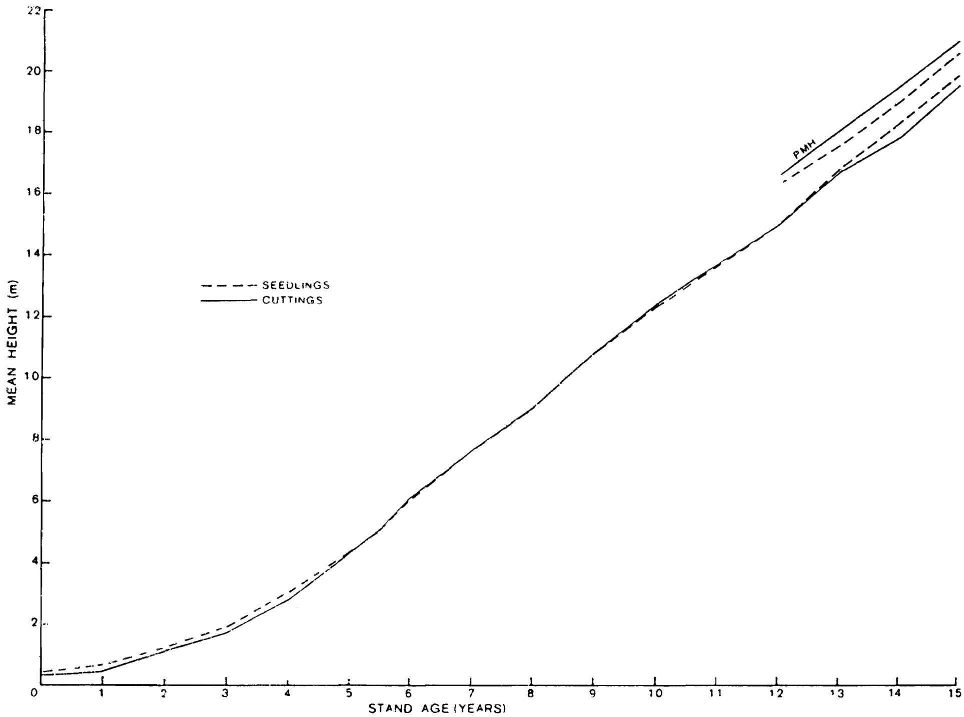

FIG. 2—Height growth of seedlings and cuttings over 15 years. Predominant mean height (PMH) is shown from year 12 on.

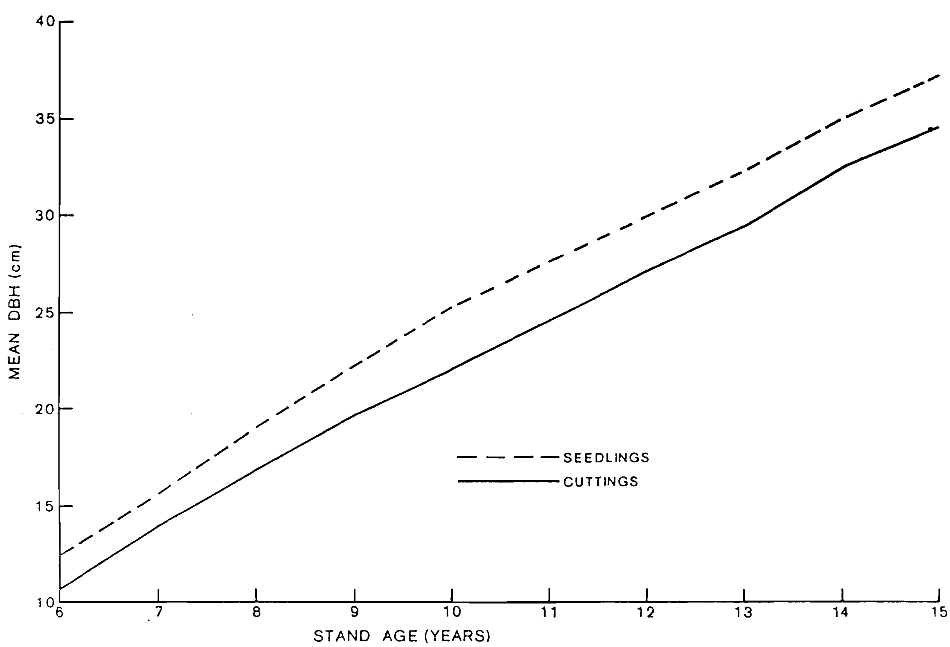

FIG. 3—Comparison of diameter growth from 6 to 15 years after planting.

Each crop tree was chosen on merit without preference for either cuttings or seedlings. The thinnings were categorised as follows:

Topples	—	trees with a lean > 15° from vertical
Runts	—	less than two-thirds mean stand height
Spacers	—	potential crop trees removed for space
Malforms	—	rejects due to malformation

A complete breakdown of thinnings (by type) and selected crop element is given in Fig. 4.

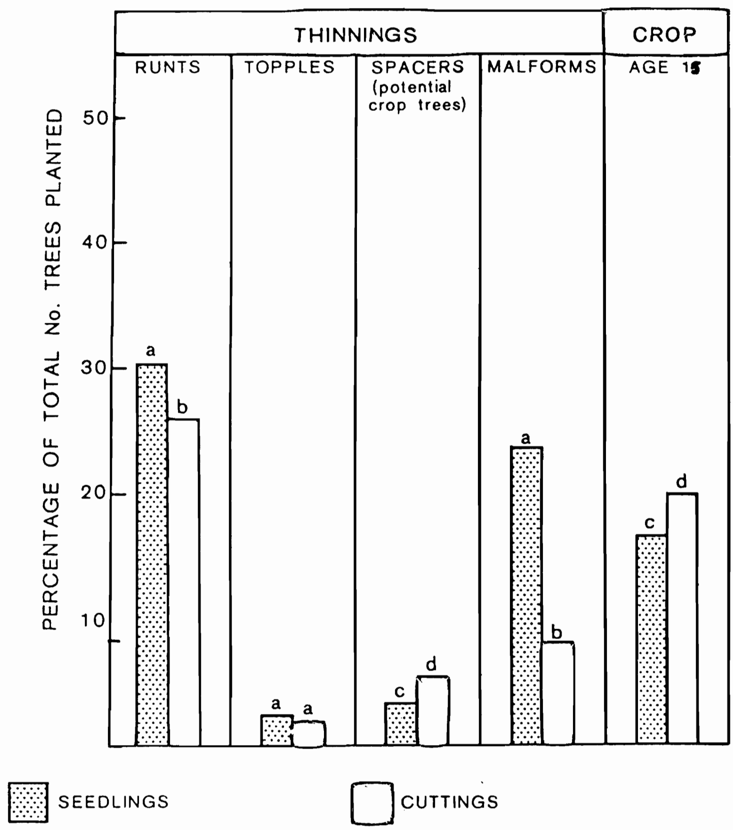

FIG. 4—Stand attrition and crop selection (0–15 years):
a and b indicate a significant difference at p = 0.01;
c and d indicate a significant difference at p = 0.05;
the same letter for both bars on the graph indicates no significant difference.

Toppling occurred during the first 6 years but the incidence in seedlings and cuttings was not significantly different. A high proportion of runts were noted at the first thinning at stand age 6 years, with seedlings having a higher proportion of runts (26%) than cuttings (20%). The removal of potential crop trees (spacers) at each thinning was minimal – a total of 3% for seedlings and 5% for cuttings. The frequency of malformed trees was consistently higher among seedlings, and the malforms for all thinnings combined was 24% for the seedlings compared with 8% for the cuttings. Collectively, the seedlings had a reject element (topples, runts, and malforms combined) of 57% removed, compared with 36% for the cuttings. The latter two comparisons were significantly different at $p = 0.01$.

Pruning

The intensity of the pruning was expressed as the proportion of pruned stem length as a percentage of total tree height (Table 1). There was no significant difference in the pruning intensity between seedlings and cuttings.

TABLE 1—Pruning intensity (percentage of stem length pruned)

	Seedlings	Cuttings
Low pruning lift	43.6	42.7
Medium pruning lift	48.2	47.2
High pruning lift	51.3	51.7
All three lifts combined	47.7	47.2

Note: The above parameters were not significantly different between seedlings and cuttings at $p = 0.05$.

Low pruning lift

Although the pruning lift to 40% tree height forms the main data base, separate recording of information up to a standard height of 2 m was also carried out.

Cuttings had fewer branches and whorls of branches, a smaller basal area of mean branch size and total branch basal area pruned, a smaller diameter over stubs (DOS), a smaller mean maximum branch diameter (within the DOS whorl), and, more importantly, took less time to prune (Table 2). All these differences were significant at $p = 0.01$. The number of branches per whorl, the height of the DOS, and the pruned height were not significantly different between seedlings and cuttings.

Medium pruning lift

A change in branching pattern occurred between the low and the medium pruning lifts. At this lift, seedlings tended to have fewer whorls and branches, although only the number of whorls was significantly different (at $p = 0.05$). The number of branches per whorl was again similar for both types but values were slightly higher than in the low pruning zone (Table 3).

TABLE 2—Comparison of seedlings with cuttings in silvicultural parameters at low pruning

Variables	Mean values: Seedlings	Mean values: Cuttings	Significance of difference
Bottom 40% tree height (2.4 m)			
No. of whorls pruned	6.5	5.4	**
No. of branches pruned	38	31	**
No. of branches per whorl	5.9	5.8	n.s.
Mean branch basal area pruned (cm^2)	4.9	4.0	**
Basal area of all branches pruned (cm^2)	183	121	**
Pruning time/tree (min)	1.8	1.2	**
Epicormic growth removal/tree (min)	0.3	0.1	**
Jacksaw used (% of trees)	64	38	
DOS (cm)	17.2	15.2	**
Mean maximum branch diameter within the DOS whorl (cm)	4.5	3.9	**
DOS height (m)	1.3	1.3	n.s.
Pruned height (m)	2.6	2.6	n.s.
Bottom 2 m			
No. of whorls pruned	6.0	4.6	**
No. of branches pruned	34	26	**
Pruning time/tree (min)	1.3	0.9	**

** Significant at p = 0.01
n.s. Non-significant at p = 0.05

TABLE 3—Comparison of seedlings with cuttings in silvicultural parameters at medium pruning to 4 m (nominal)

Variables	Mean values: Seedlings	Mean values: Cuttings	Significance of difference
No. of whorls pruned	3.0	3.5	*
No. of branches pruned	20	23	n.s.
No. of branches per whorl	6.8	6.5	n.s.
Mean branch basal area (cm^2)	10.6	7.5	**
Basal area of all branches pruned (cm^2)	203	159	**
Pruning time per tree (min)	3.6	2.7	**
DOS (cm)	20.8	18.5	**
Mean maximum branch diameter within the DOS whorl (cm)	5.4	4.5	**
DOS height (m)	2.7	2.7	n.s.
Pruned height (m)	4.3	4.3	n.s.

** Significant at p = 0.01
* Significant at p = 0.05
n.s. Non-significant at p = 0.05

Mean branch basal area, basal area of all branches pruned, DOS, mean maximum branch diameter (in DOS whorl), and pruning time per tree all showed lower values for cuttings, which was a similar result to that for the low pruning lift. These latter differences were significant at $p = 0.01$.

High pruning lift

The branching pattern in the high pruning zone was similar to that of the medium zone and contrasted to that of the low pruning zone. Seedlings had fewer whorls and branches, but this time both differences were significant at $p = 0.01$ (Table 4). However, the number of branches within a whorl was again not significantly different.

Although cuttings still had a smaller total basal area of branches pruned and a smaller mean maximum branch diameter (within the DOS whorl), the differences were not significant for this lift. Mean branch basal area, DOS, and pruning time per tree were significantly higher for the seedlings at $p = 0.01$, as they had been for the other two lifts also.

TABLE 4—Comparison of seedlings with cuttings in silvicultural parameters at high pruning to 6 m (nominal)

Variables	Mean values		Significance of difference
	Seedlings	Cuttings	
No. of whorls pruned	3.5	4.2	**
No. of branches pruned	23	27	**
No. of branches per whorl	6.7	6.4	n.s.
Mean branch basal area (cm^2)	11.3	8.5	**
Basal area of all branches pruned (cm^2)	250	215	n.s.
Pruning time per tree (min)	4.8	3.9	**
DOS (cm)	23.8	21.5	**
Mean maximum branch diameter within the DOS whorl (cm)	5.7	5.2	n.s.
DOS height (m)	4.4	4.5	n.s.
Pruned height (m)	6.3	6.3	n.s.

** Significant at $p = 0.01$
n.s. Non-significant at $p = 0.05$

Regression of DOS on d.b.h. for seedlings and cuttings

Regressions of DOS on d.b.h. were analysed and compared for seedlings and cuttings, using the pruning data.

The results showed that DOS is highly correlated with d.b.h. both in seedlings ($r = 0.79$, 0.82, and 0.83) and in cuttings ($r = 0.84$, 0.84, 0.93) at each pruning lift and the regressions between the two stock types are not significantly different either in the slopes or in the levels (Fig. 5).

Therefore, the larger DOS in seedlings (Tables 2, 3, and 4) is due to their larger d.b.h.

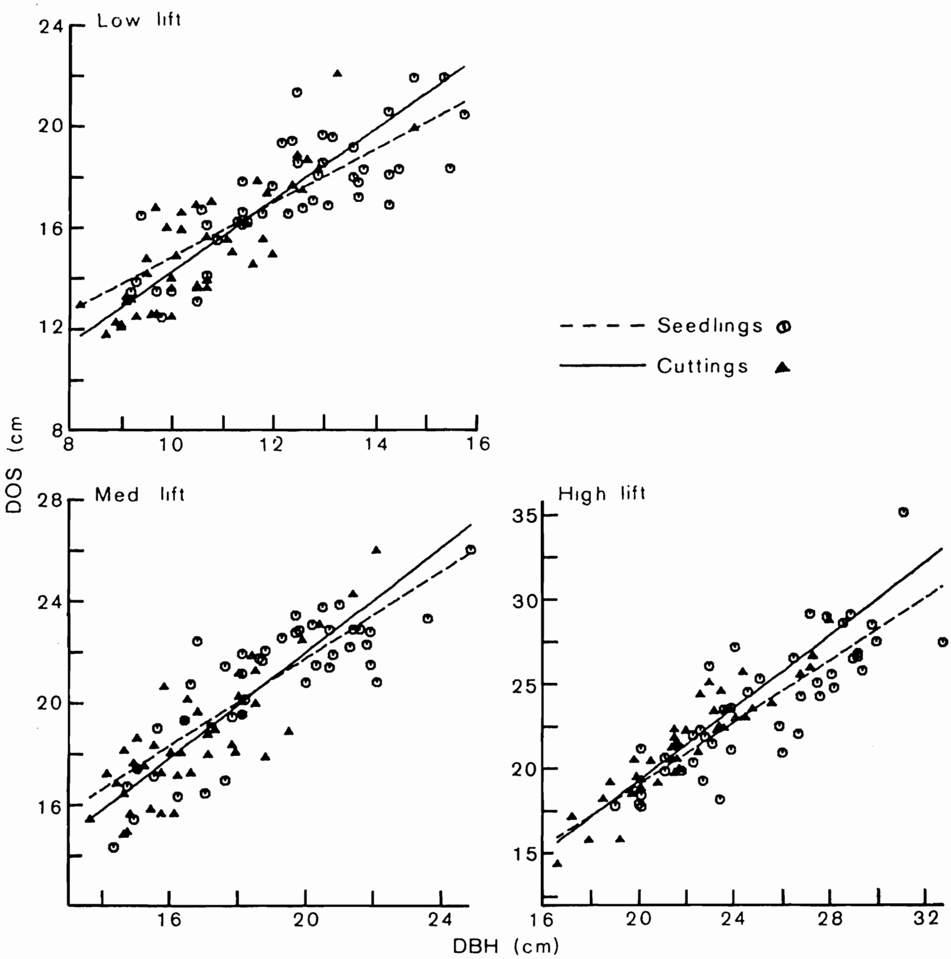

FIG. 5—Comparison of regressions of DOS on d.b.h. between seedlings and cuttings.

Note: The regressions between the two tree types are not significantly different either in the slopes or in the levels at any pruning lift.

Correlation between pruning time and other parameters

In order to find the relationship between pruning times and number of whorls, number of branches, maximum branch diameter within the DOS whorl, basal area of all branches pruned, d.b.h., and DOS, correlation analyses were carried out. Neither branch nor whorl number was consistently related to the pruning time (Table 5). There was a moderate correlation only at the low lift but the extent of correlation became relatively weak at the medium and high pruning lifts. Conversely, the basal area of all branches pruned per tree showed a consistent relationship with the pruning times, as did the maximum branch diameter, d.b.h., and DOS.

TABLE 5—Correlation coefficients between pruning time per tree and other variables – seedlings (S) compared with cuttings (C)

Variables	Pruning time per tree					
	Low lift		Medium lift		High lift	
	S	C	S	C	S	C
No. of branches pruned	0.54**	0.53**	0.31*	0.44**	0.29	0.14
No. of whorls pruned	0.43**	0.46**	0.14	0.36*	0.21	0.15
Maximum branch diameter within the DOS whorl	0.47**	0.66**	0.43**	0.56**	0.51**	0.46**
Basal area of all branches pruned	0.86**	0.86**	0.85**	0.86**	0.79**	0.87**
DOS	0.68**	0.71**	0.53**	0.63**	0.75**	0.59**
d.b.h.	0.59**	0.58**	0.47**	0.41**	0.62**	0.46**

* Significant at p = 0.05
** Significant at p = 0.01

Comparison of regressions of pruning time on basal area of all branches pruned and d.b.h. between seedlings and cuttings.

No significant difference was found in the slopes of regressions between the two tree types but the regression level of seedlings was significantly higher than that of cuttings at all lifts, indicating that seedlings take longer to prune than cuttings for the same basal area of all branches pruned (Fig. 6).

As d.b.h. has shown a high correlation with basal area of all branches pruned and with pruning time (Tables 5 and 6), and is also a commonly used parameter in forest management, regressions of pruning time on d.b.h. were compared between seedlings and cuttings (Fig. 7). The slopes of regressions of the two tree types did not differ significantly. However, seedlings showed a significantly higher level than cuttings at the low pruning lift ($p = 0.01$) and at the medium lift ($p = 0.05$). The high lift did not show any difference in the regression between the two types. This result implies that cuttings take less time to prune than seedlings for trees with the same d.b.h. at the low and medium lifts.

DISCUSSION

The quality of planting stock, particularly *P. radiata* cuttings, has undoubtedly improved since 1970 when this trial was established. Nevertheless, as an early indicator of the performance of rooted cuttings compared with seedlings, the results of this trial are of considerable value. The indigenous cutover site with its inherent survival problem due to Armillaria root rot has provided an important insight into the susceptibility of *P. radiata* cuttings to the disease. It is clear that the cuttings sustained heavier losses from Armillaria than did seedlings and this agrees with a report by Beveridge (1974). However, the effect of Armillaria-related mortality rapidly diminished 5 years after planting and this phenomenon has also been reported earlier by Beveridge (1974),

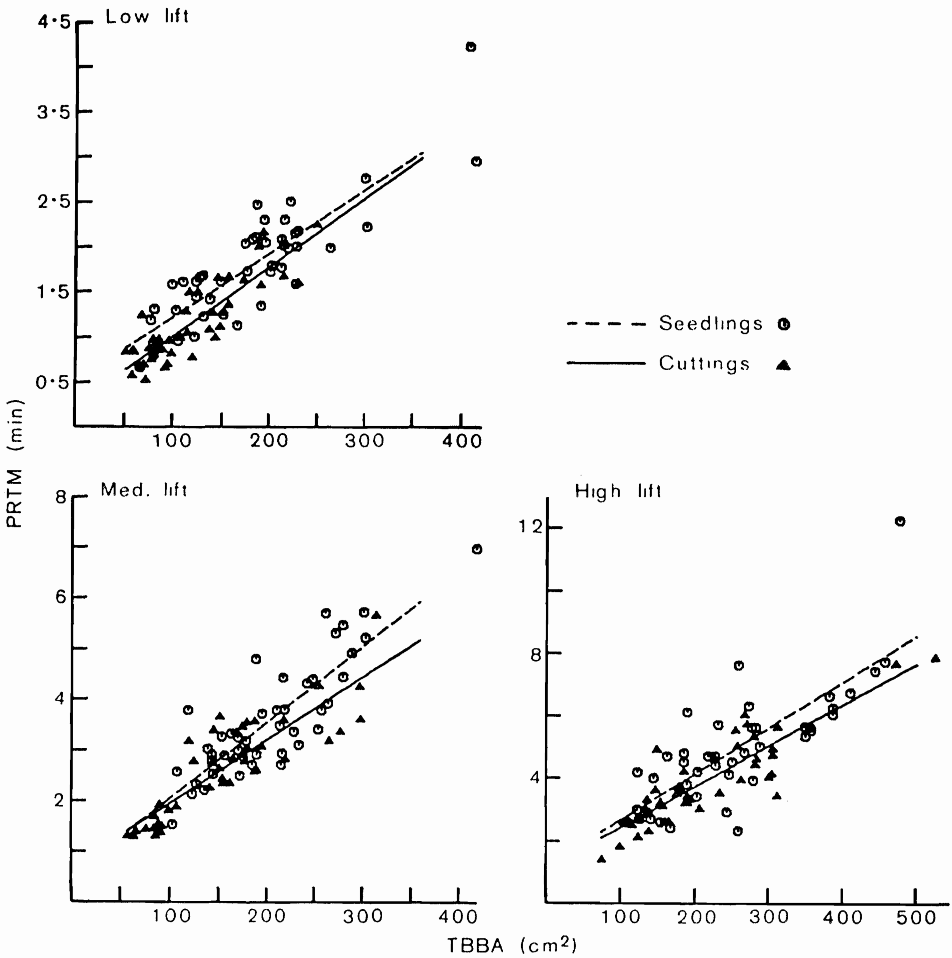

FIG. 6—Comparison of regressions of pruning time (PRTM) on basal area of all branches pruned (TBBA) between seedlings and cuttings.
Note: There are no significant differences in the slopes but seedlings show a significantly higher level than cuttings at all three pruning lifts.

TABLE 6—Correlation coefficients between basal area of all branches pruned and DOS or d.b.h.

Variables	Type	Basal area of all branches pruned		
		Low lift	Medium lift	High lift
DOS	Seedlings	0.80**	0.53**	0.81**
d.b.h.	Seedlings	0.68**	0.43**	0.77**
DOS	Cuttings	0.81**	0.73**	0.67**
d.b.h.	Cuttings	0.60**	0.48**	0.58**
DOS	S & C comb.	0.83**	0.67**	0.76**
d.b.h.	S & C comb.	0.72**	0.52**	0.68**

** Significant at p = 0.01

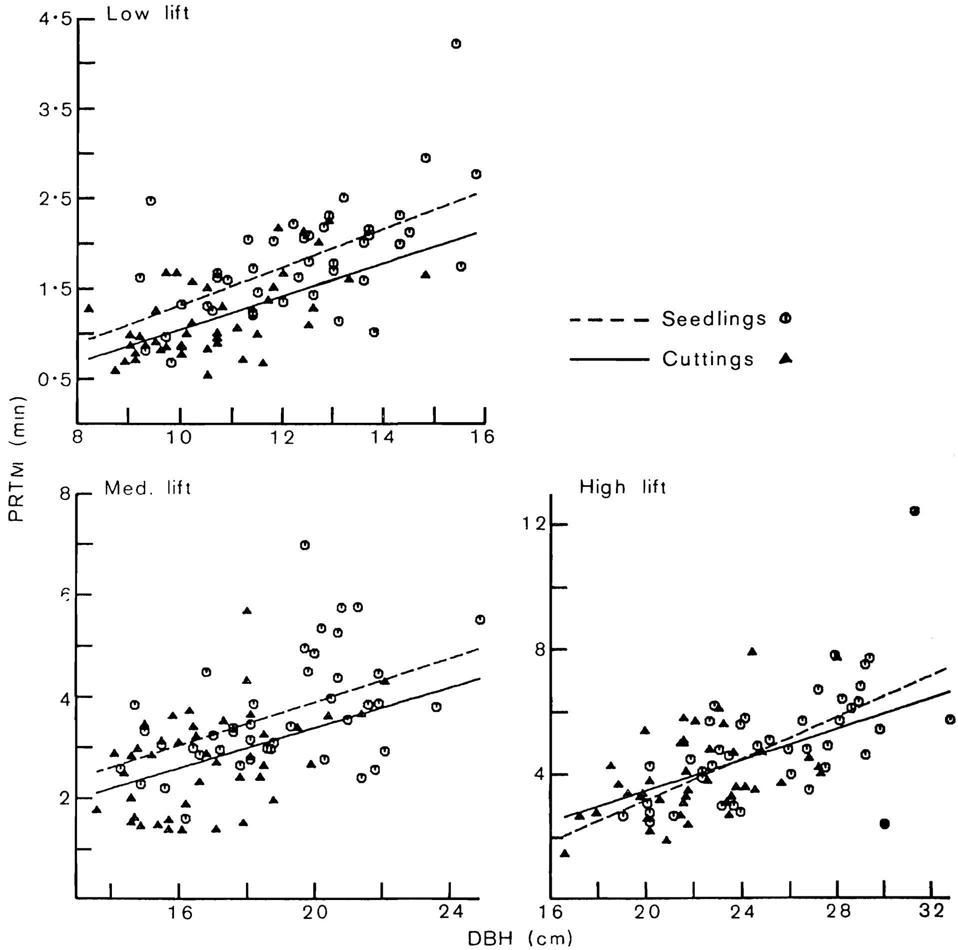

FIG. 7—Comparison of regressions of pruning time (PRTM) on d.b.h. between seedlings and cuttings.

Note: Regression slopes are not significantly different at all pruning lifts; however, seedlings show a significantly higher level than cuttings at the low and medium pruning.

Shaw & Calderon (1977), and MacKenzie & Shaw (1977). It remains to be seen if the improved planting stock of cuttings currently being produced has a better survival rate than that achieved in this trial. It is likely that rooted cuttings from younger ortets (less than 4 years) will be used in future plantings and these may well be more resistant to the disease.

In this field trial, there was no significant difference in height growth between seedlings and cuttings up to stand age 15 years, and this is in agreement with other published results by Brown (1974) testing ortet ages 1, 2, 3, and 7 for 3 years after planting, Tufuor (1974) testing ortet ages 5, 10, 11, 12, and 14, up to 5 years after planting out, and West (1984) using ortet age 5 and also measuring up to 5 years. However, Shelbourne & Thulin (1974) and Sweet & Wells (1974) found that cuttings had a lower height growth than seedlings up to 6 years after planting.

Cuttings had a significantly smaller diameter at breast height (i.e., 1.8 cm smaller than seedlings when measurements began at stand age 6 years). This difference increased to 2.6 cm at plantation age 15 years, although the final three annual measurements showed no significant difference in diameter increment. The loss in diameter growth by cuttings compared with seedlings (Shelbourne & Thulin 1974; Tufuor & Libby 1973; West 1984) and its negative relationship with ortet age (Sweet & Wells 1974) has been widely reported, although Fielding (1970) and Brown (1974) found little difference in diameter growth between the two stock types.

On similar sites at Mamaku, Shaw & Toes (1977) detected a loss in diameter growth in *P. radiata* infected with Armillaria root rot compared with non-infected trees. Much of this Armillaria infection at plantation age 10 years or more appeared to be sub-lethal and was not easily detected by inspection of the tree crown. If the higher incidence of Armillaria recorded in the first 5 years on the trial site continued, it is possible that Armillaria contibuted to the loss in diameter growth of the cuttings to some extent.

Bulk cuttings from mature or adolescent ortets have a definite advantage over seedlings in form, particularly stem straightness, and this is supported by almost all of the work published previously. In this study, the number of trees rejected because of malformation and lack of size was significantly higher among seedlings.

It is generally well known that cuttings from older ortets lack the typically juvenile appearance of seedlings in the early stages of growth. The more mature growth habit of cuttings probably explains why they had fewer branches in the low pruning zone compared with seedlings in our study, and this was also confirmed by Tufuor & Libby (1973). In contrast, cuttings have a similar number of branches to seedlings in the medium zone but a higher number in the high pruning zone. However, the pruned butt log taken over-all (0–6 m) had a similar number of branches and whorls for both plant types and the main difference was in branch size, as seedlings had a significantly larger mean branch basal area.

Probably the two most important parameters affecting the cost of silvicultural operations are the pruning times per tree and the DOS measurements. Seedlings took significantly longer to prune than did cuttings for all three lifts. Tufuor & Libby (1973) also reported longer pruning times for seedlings in a 1.5-m pruning lift. Seedlings also had a larger DOS in all three pruning lifts, as could be expected from their larger d.b.h.

The correlation and regression analyses on pruning times and silvicultural parameters showed that basal area of all branches pruned was strongly related to pruning time per tree. Furthermore, d.b.h. had a strong relationship with basal area of all branches pruned and hence pruning time per tree. An interesting point is that seedlings have shown a longer pruning time than cuttings for the same basal area of all branches pruned or for the same size of d.b.h., particularly at the low and medium pruning lifts. This is probably because seedlings have a larger maximum branch diameter within the DOS whorl than cuttings. The maximum branch size is used as a good indicator of pruning time with regard to contract rate setting by the Work Study Unit of the New Zealand Forest Service (M. Fielder, pers. comm.). As d.b.h. is being measured by forest management on a wide scale, it could be used to predict pruning costs if this relationship holds for a range of sites and silvicultural regimes.

In conclusion, the trial has shown that rooted cuttings have some silvicultural advantages when compared with seedlings – e.g., lower stockings required at planting because of less malformation, smaller branch size, lower pruning times, and greater uniformity in size. Numerous other trials comparing cuttings and seedlings have subsequently been planted. It will, therefore, soon be possible to evaluate more comprehensively whether cuttings have any economic advantage over seedlings.

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