GROWTH AND PREDICTED TIMBER VALUE OF *PINUS RADIATA* CUTTINGS AND SEEDLINGS ON A FERTILE FARM SITE

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ABSTRACT

Pinus radiata D. Don cuttings from 3-year-old donor trees were compared with seedlings in a spacing trial planted on farmland near Rotorua and grown on a direct sawlog regime. At age 7 years, the cuttings were taller but slimmer and had less taper than the seedlings. Closer spacing at planting enhanced height but not diameter growth for both stock types. The most pronounced contrast between the two stock types was the better resistance to toppling and superior form, particularly straightness, of the cuttings. This trend had a marked effect on crop selection ratios, resulting in the need to plant at least double the number of seedlings to approach the crop quality of the cuttings. PC-STANDPAK was used to model results at plantation age 28 years. It was predicted that the superior shape and form of the butt log of the cuttings would result in a substantially higher recoverable volume of clear grade timber than the seedlings. Consequently, the value of pruned logs per hectare for the cuttings was predicted to be 20% higher than that for the seedlings. This trial was planted on a fertile site, and early differences in form between seedlings and cuttings were more pronounced than observed at less fertile sites. However, the results observed here could be expected on other highly fertile sites.

Keywords: cuttings; seedlings; predicted value; *Pinus radiata*.

INTRODUCTION

If a superior tree is vegetatively reproduced via rooted cuttings, these cuttings retain the superior parental genotype. This concept has been utilised for practical forestry in some timber species for hundreds of years (Toda 1974) and has also been applied to tree improvement programmes of many species in many countries since the late 1940s.

Early trials with cuttings from 5- to 24-year-old ortets of *Pinus radiata* (Fielding 1970; Pawsey 1971) found that trees grown from cuttings have morphological differences such as thinner bark, less taper, lighter and fewer branches, and straighter stems than seedling-grown trees at an equivalent age after planting. It was also found that cuttings are not inferior to seedlings in height growth unless their ortet age is more than 15 years.

As the techniques to mass produce rooted cuttings from *P. radiata* ortets up to 15 years of age were developed (Thulin & Faulds 1968), some forest scientists foresaw the possibility of utilising these advantages of cuttings for the establishment of commercial plantations of

P. radiata (Fielding 1964; Franclet 1966; Thulin & Faulds 1968). However, in spite of these technical developments and suggestions, large-scale planting programmes using *P. radiata* cuttings were started in Australia (Clarke & Slee 1984) and in New Zealand (Arnold & Gleed 1985) only in the early 1980s.

While cuttings obviously have many advantages, they have disadvantages as well which vary in degree depending on ortet age. These include loss of rooting ability (Brown 1974; Thulin & Faulds 1968), reduction in diameter growth (West 1984; Klomp & Hong 1985; Menzies & Klomp 1988), and higher production costs (Arnold & Gleed 1985; Menzies *et al.* 1988). However, the loss of rooting ability has been observed only when cutting material was taken from trees older than 10 years of age (Thulin & Faulds 1968; Menzies & Klomp 1988). Also, the reduction in diameter growth of trees grown from cuttings does not necessarily mean reduction in volume of the trees because they have less taper and thinner bark, and thus greater volume per unit of basal area, particularly with cuttings grown from older ortets, than stands of seedling origin (Pawsey 1971).

Trees grown from cuttings also have silvicultural and utilisation advantages such as less malformation (Klomp & Hong 1985), higher frequency of acceptable stems and, therefore, lower planting density and lower pruning costs (Klomp 1988), and a higher quality of timber (Arnold & Gleed 1985; Spencer 1987) compared with trees grown from seedlings.

Recently, a series of trials was established in New Zealand to evaluate the comparative performance of various propagule types, as well as the optimum age of ortets for achieving improvement in tree form without loss of growth (Klomp & Menzies 1988; Menzies & Klomp 1988). From the early results of the trials, the optimum age of donor trees was considered to be 3 years. With an ortet age of 3, many of the advantages of physiologically-aged cuttings can be obtained without incurring those disadvantages that become apparent with increasing ortet age.

This paper reports on growth performance, selection ratios (proportion of acceptable crop trees before and after thinning based on initial stocking), and form assessments up to age 7 years after planting, of cuttings taken from ortets aged 3 years, compared with seedlings of equivalent genetic origin. The form assessments included sweep and taper measurements of the pruned (5.5-m) butt log. These data were used to predict yields and timber values for the pruned butt logs using PC-STANDPAK, an integrated computer-based modelling system developed by the New Zealand Forest Research Institute.

This trial was part of a series of trials testing the performance of seedlings and cuttings (Appendix 2). Data from this trial were chosen for the STANDPAK analyses because the high-fertility site produced fast early growth that leads to considerable stem malformation (i.e., sweep) and it was considered important not only to get a physical measurement on the amount of sweep, but also to attempt to quantify the effect of sweep on log value. It was evident from a preliminary study, which used STANDPAK to examine the effect of sweep on log value, that relatively large differences in mean sweep between crops were needed to have any significant effect on log value. Although other studies (Carson 1987) have examined the broad sensitivity of profitability and timber grade outturns to changes in log sweep, very little work has been done using actual measurement data. Also, the large block design of this trial allowed for a greater number of trees to be measured than are available in similar trials of row plot design.

MATERIALS AND METHODS

Raising of Planting Stock, Site, and Trial Design

Cuttings were collected in June from 3-year-old trees in the field. The selection criterion was that the parent tree be healthy, and no consideration was given to either form or growth. Cuttings were set in nursery beds at 7.5 × 15-cm spacing and were given a conventional root-pruning regime until lifting the following winter.

Seedlings were raised as normal 1/0 seedling stock at a spacing of 6 × 12.5 cm.

The 14-ha trial was planted in July 1984 on farmland at Valley Road, Rotorua, on the lower slopes of Mt Ngongotaha. The site had a north-north-west aspect on slopes of 5–30° and the soil was a yellow-brown loam. The experimental design was a randomised complete block with two stock types and three planting densities (Table 1), replicated in five blocks. Each plot was 0.21 ha in area with a one-row buffer, resulting in a measurement plot size of 0.1 ha. Within each block there were extra replicates of each initial stocking, intended to be used for alternative silvicultural regimes. At the time of final pruning no other regimes had been implemented. The complete trial consisted of 70 plots.

TABLE 1–Stock type, genetic origin, and spacing

Stock type	Genetic origin	
1/0 seedlings	Special "268" collection, seedlot 9/0/83/082, GF15	
0/1 cuttings (from 3-year-old donor trees)	"268" × "875" tree improvement trial, GF16	
Initial stocking (stems/ha)	**Spacing (m)**	**No. trees/measurement plot**
200	7.15 × 7	20
400	5 × 5	42
600	4.08 × 4.08	72

Establishment

After short-grazing of the pasture, circular planting spots of 1.5 m in diameter were sprayed with a Gramoxone/simazine mixture 1 month before planting. Planting was done by hand using a planting spade and applying a wedge technique with cultivation if necessary.

Grazing Management

The trial was grazed for the first time in September 1986, 2 years after establishment. Two-thirds of the trial was mob stocked with ewes which were left in over a long weekend and some damage occurred, particularly stem debarking. Subsequent grazing with fewer sheep proved to be more successful and a combination of sheep and beef cattle caused no further problems. Long-term effects of the early damage were considered negligible.

Silvicultural Management

First-lift pruning was carried out as a variable lift to half tree height at age 3.5 years after planting. This operation was immediately followed by a thinning down to 300 stems/ha in the plots with 400 and 600 stems/ha initial stockings. The basic criteria were selection on form first, then selection on size, and then espacement. The plots planted at 200 stems/ha were cull-thinned for unprunable stems only.

Subsequent pruning lifts, specified to leave 3 to 3.5 m of green crown, were carried out at ages 4.5, 5.5, and 6.5 years. No further thinnings were scheduled, although small numbers of unprunable trees were removed after the second- and third-lift pruning operations. This resulted in the nominated 200 stems/ha stocking being somewhat less (Fig. 1) and many of the 400 and some of the 600 stems/ha stockings did not achieve the nominated target of 300 stems/ha, 7 years after planting (Table 2).

FIG. 1–Cutting/seedling spacing trial, Valley Road, Rotorua, initial stocking 200 stems/ha. *Left*: seedlings, 1992 stocking = 110 stems/ha. *Right*: cuttings, 1992 stocking = 170 stems/ha.

TABLE 2–Stocking rates (stems/ha)

	Cuttings			Seedlings		
Initial, at planting	200	400	600	200	400	600
Nominated, at thinning	200	300	300	200	300	300
Actual, at 7 years	162	273	289	117	196	270
Range, at 7 years	120–190	230–300	270–300	80–170	120–280	230–300

Assessment of Butt Log Form Factors

In addition to dbhob, height, and pruned height, sweep and taper were measured after the fourth pruning lift.

Within each block, one plot per treatment was selected at random for measurement of sweep. Extra plots were measured in the 200 stems/ha treatment to ensure that at least 100 trees per treatment were available for analyses. Sweep was measured in the 5.5-m pruned butt log on all trees in the plot, using an aluminium straight-edge. The point of maximum deviation from straight was measured on the outside edge of the tree allowing for a stump height of 0.3 m.

For analysis, the juvenile sweep values were converted to mature log sweep values using a relationship derived from sawing study data (J.Tombleson and N.Woods, pers. comm.). It relates deviation in the pith and defect core to outside sweep deviation in mature logs and is calculated as:

$$\text{Mature sweep} = \text{Juvenile sweep} \times 0.6849 + 0.2184$$

In simple terms, this implies that the amount of sweep in the butt log, measured at the time of final lift pruning, is predicted to be reduced by approximately 30% at the time of harvest. All butt logs with a converted (mature) sweep measurement of 0–6 mm/m log were included in the "straight" category. Analyses compared mean (mature) sweep and percentages of "straight" logs for each of the treatments. Percentage data were transformed by angular transformation where necessary.

Trees measured for sweep were also measured for taper; however, trees that were unpruned or multi-leadered below a height of 5 m were excluded from measurement. At least 100 trees per treatment were measured. Taper was calculated from the diameters measured overbark at 1.4 m (dbhob) and 5.0 m and expressed in millimetres per metre of log.

PC-STANDPAK Evaluation

PC-STANDPAK (Whiteside 1990) was used to predict butt log timber yield and value for cuttings and seedlings. The same models and assumptions (Appendix 1) were used for both seedlings and cuttings, except where actual measurements were available. Actual measurements included height, dbh, pruning, and stocking regimes in GROSTAND (growth simulation program), juvenile sweep values in LOGASORT (felling and cross-cutting simulation program), and mature sweep values in SAWMOD (sawlog evaluation model) (Appendix 1).

To run the growth simulation program in STANDPAK, the site index was calculated (using the EARLY growth model, West *et al.* 1982) from the last height available (at age 7 years) and predicted to be 31.7 m for the cuttings and 30.9 m for the seedlings. Using these inputs, EARLY then grew the stand to a mean height of approximately 18 m, after which the NAPIRAD (Goulding 1995) growth model derived predicted stand height and basal area (BA) at age 28 years.

The basal area level in GROSTAND was set to "High + 20%" for both stock types, based on the site being highly fertile, and a comparison was made between predicted basal area and actual basal area at age 7 years. This indicated that basal area growth was under-predicted by the model for both cuttings and seedlings at age 7 years. The initial (age 4 years) basal area was, therefore, increased to bring the predicted and actual basal area values at age 7 years into line (Table 3).

TABLE 3–Errors in height and basal area as a percentage of predicted values

Age	Seedlings						Cuttings					
	Act* HT	Pred† HT	Error (%)	Act BA	Pred BA	Error (%)	Act HT	Pred HT	Error (%)	Act BA	Pred BA	Error (%)
4	5.3	5.3	0	2.55	3.12	−18.3	5.6	5.6	0	2.17	2.36	−8.0
4.5	5.6	5.6	0	4.29	4.42	−2.9	5.9	5.9	0	3.80	3.55	7.0
5	6.9	7.0	−1.4	7.83	7.85	−0.2	7.5	7.4	1.3	7.05	6.66	5.8
6	8.7	8.6	1.2	9.94	9.74	2.0	9.3	9.0	3.3	9.08	8.50	6.8
7	10.1	10.2	−1.0	11.41	11.40	0.1	10.7	10.7	0	10.46	10.46	0

* Act HT or Act BA stands for actual height or actual basal area.

† Pred HT or Pred BA stands for predicted height or predicted basal area.

Increasing the initial values would better reflect the diameter-over-stubs (DOS) and maximum branch diameter and thus defect core size, all of which have considerable influence on the sawn grade outturn of the higher value clear grade timber. The percentage error for both height and basal area (following adjustment) are minimal at the age of 7 years (Table 3).

A separate run of STANDPAK was made for each stock type, and run through to SAWMOD to derive log yields, timber grade outturn and value.

Statistical Analyses

An analysis of variance (ANOVA) was performed on plot values (percentages or means). Incidences of sweep, stem or leader defects, and topples, and numbers of crop trees were calculated as a percentage of the initial number of trees planted per plot. Plot means were used for height, dbh, and sweep analyses. Percentage data were transformed by angular transformation where necessary.

The ANOVA was based on the following model:

$$Y_{ijk} = u + T_i + P_j + (TP)_{ij} + B_k + e_{ijk}$$

where $i = 1,2, \quad j = 1....3, \quad k = 1....5$

Y_{ijk} = plot value of stock type i, spacing j, and block k

u = overall mean

T_i = effect of stock type i

P_j = effect of spacing j

$(TP)_{ij}$ = interaction effect of stock type i and spacing j

B_k = effect of block k, and

e_{ijk} = random error related to Y_{ijk}

RESULTS

Statistical Analyses

Analyses of variance for all the variables have shown little evidence of an interaction between stock type and spacing. When the effect of spacing was significant at the 5% level, an LSD (least significant difference) test was carried out to compare the means. Analyses of covariance for height and dbh at 7 years after planting were performed using the initial planting height as a covariate. A test for slope differences was not significant, indicating that a common slope could be assumed. The covariate was significant for dbh but not height. However, the significance of stock type and spacing was not affected by the covariate adjustment.

Earlier results, up to age 5 years after planting, have been published previously (Menzies *et al.* 1991) but a brief summary of this information is warranted.

Early Malformation Traits

Superior form in the cuttings was evident during the first growing season in the field. The incidence of "speed wobble" 18 months after planting was significantly higher ($p<0.001$) amongst the seedlings (45%) than the cuttings (16%). Speed wobble is a type of malformation consisting of stem and branch twisting (Will 1986). The occurrence of toppling was also higher amongst seedlings.

All trees were visually assessed for defects at age 4 years, prior to first crop selection and thinning (Fig. 2).

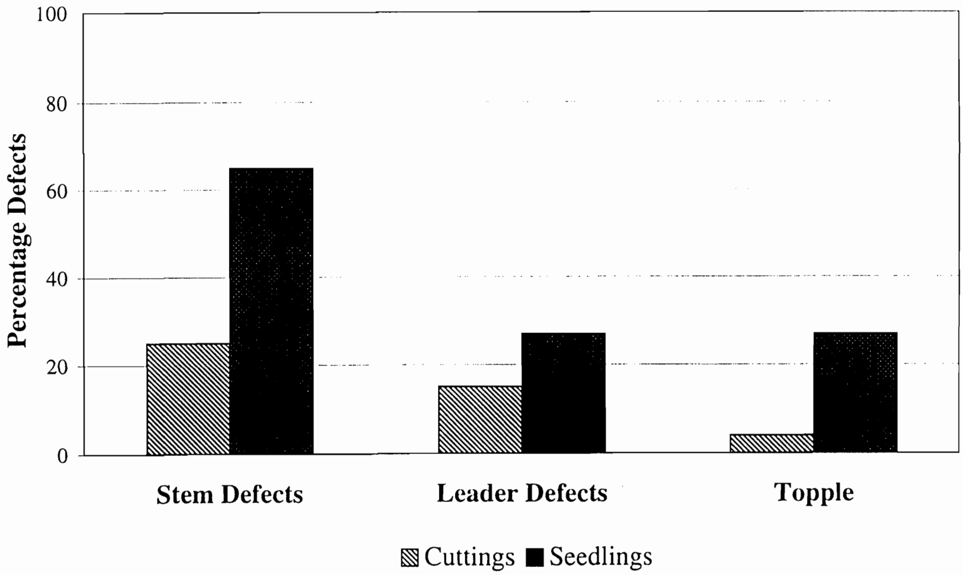

FIG. 2–Percentages of tree defects before thinning at age 4 years after planting (Menzies *et al.* 1991)

The cuttings had significantly fewer stem defects (25% *v.* 65%, $p<0.001$) and leader defects (15% *v.* 27%, $p<0.001$) and had also toppled less than seedlings (4% *v.* 27%, $p<0.001$). This had a profound effect on selection of the potential crop element, as the cuttings had a significantly higher ($p<0.001$) proportion of acceptable crop trees than the seedlings before thinning (Fig. 3).

Growth Comparisons

Growth comparisons, at age 7 years, are shown in Table 4 for both stock types at the three different initial stockings.

The cuttings were significantly taller than the seedlings but had a significantly smaller dbh. Trees were significantly taller in plots at higher initial stockings, but there was no significant difference in dbh among the three stockings. There was no significant interaction between stock types and initial stockings. Because cuttings were taller, they were pruned higher.

Quality Comparisons

Sweep and taper were the quality factors measured on the 5.5-m pruned butt logs after the fourth pruning lift at 7 years after planting.

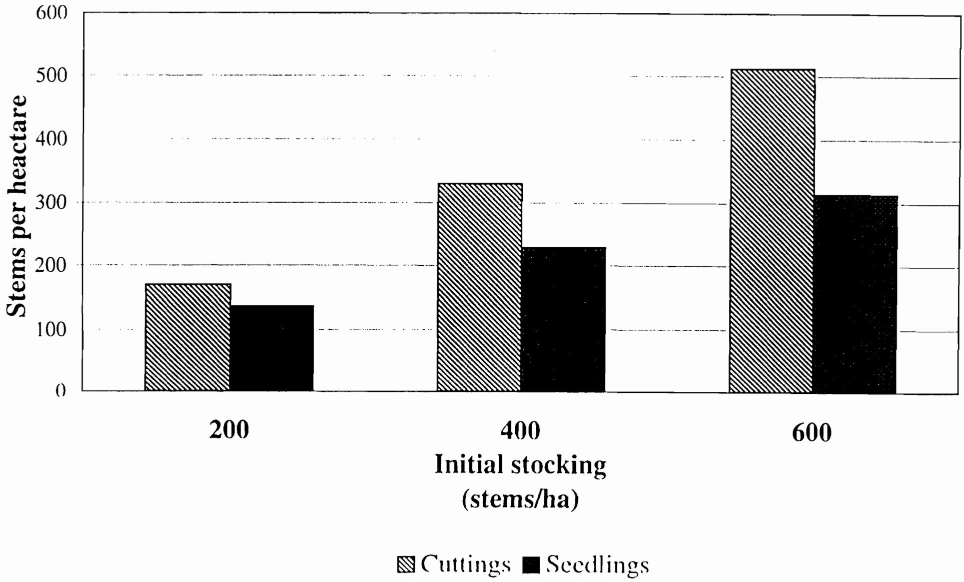

FIG. 3–Number of acceptable crop trees per hectare before thinning at age 4 years after planting (Menzies *et al.* 1991).

TABLE 4–Mean height, pruned height, and dbh at age 7 years

	Height (m)	Pruned height (m)	dbh (cm)
Stock type			
Seedlings	10.1 b	5.6 b	25.7 a
Cuttings	10.7 a	6.0 a	24.6 b
Stocking (stems/ha)			
600 (300)	10.8 a	6.0 a	25.5 ns
400 (300)	10.5 b	5.9 a	25.1 ns
200	10.0 c	5.5 b	25.0 ns

Means followed by the same alphabetical letter are not significantly different (LSD test, p = 0.05). Final stockings in parentheses.

Sweep

After conversion of the sweep data to mature sweep values, all butt logs with a converted (mature) sweep measurement of 0 to 6 mm/m log were included in the "straight" category. The percentage of straight butt logs was significantly higher ($p<0.001$) for cuttings (71% overall) than for seedlings (30% overall) for all three initial stockings (Fig. 4).

The cuttings had a significantly lower estimated mean sweep value in the 5.5-m butt logs than the seedlings. The trend was consistent over all three initial stockings (Table 5). The mean values for the percentage of swept trees and mean sweep are important in STANDPAK as they influence predicted log value.

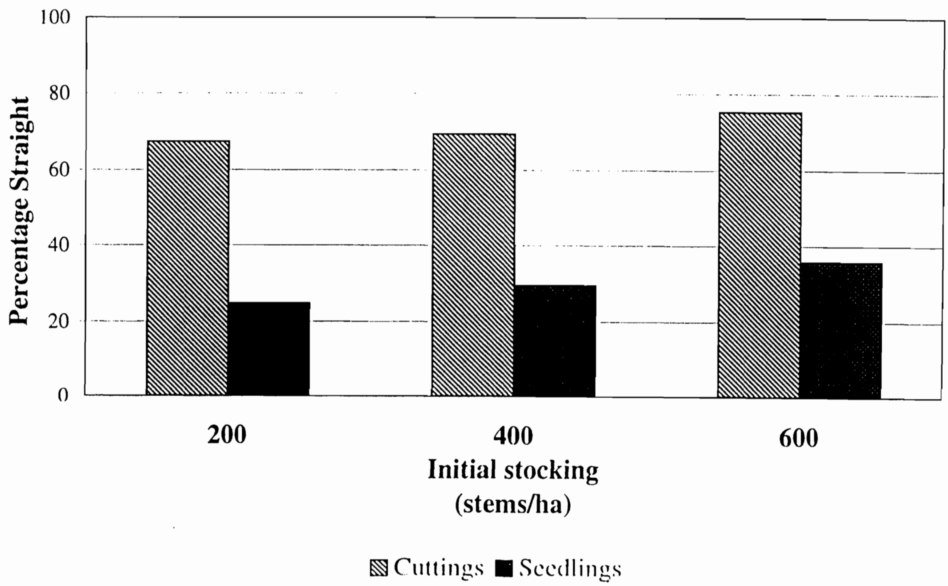

FIG. 4—Percentages of butt logs with sweep up to 6 mm/m estimated for mature logs, based on data collected at age 7 years after planting

TABLE 5—Mean sweep estimated in 5.5-m mature butt logs (mm/m)

Stock type	Initial stocking (stems/ha)			Mean
	200	400	600	
Seedlings	10.0	9.2	8.2	9.2**
Cuttings	3.8	4.2	3.1	3.7

**Significantly higher than that of cuttings at p<0.001

Taper

Taper (mm/m) was calculated from the over-bark diameters measured at 1.4 m and 5.0 m. The cuttings had significantly less taper (23 mm/m) than the seedlings (29 mm/m) ($p<0.001$). This trend was consistent over all three initial stockings (Fig. 5). The calculated taper values were not used in the STANDPAK analysis, however, since mature log (at harvest) taper values are considerably less than the values obtained at age 7 years. The relationship between changes in taper over time is not clearly understood.

Selection of the Final Crop

The superior form of the cuttings was evident at the first thinning 4 years after planting. Consequently, crop selection ratios for cuttings were significantly better than for seedlings (Menzies *et al.* 1991).

In using form as the main selection criterion for thinning, it was apparent that the slight reduction in mean diameter for cuttings may have occurred simply due to the superior straightness of the cuttings. Straighter trees are often the smaller trees. A simulated thinning

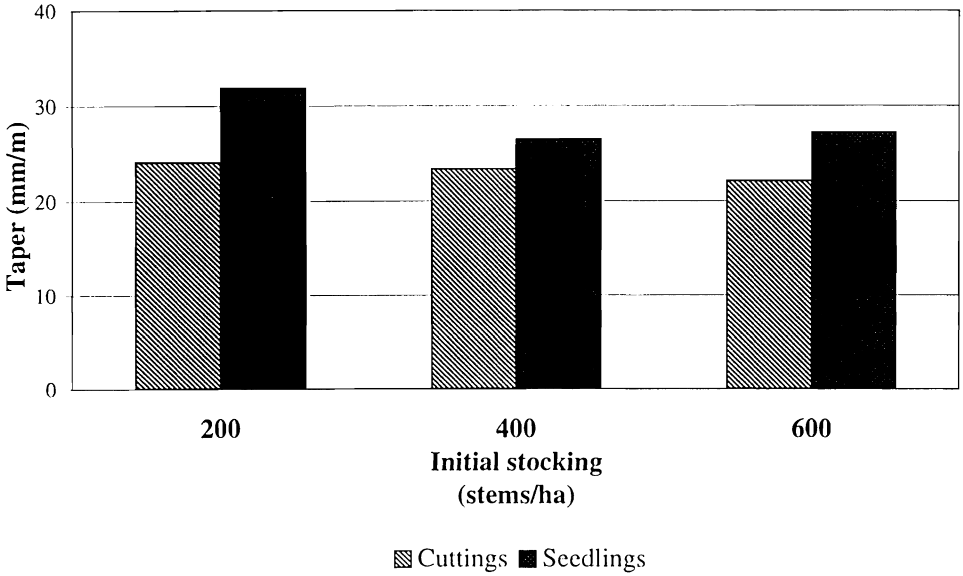

FIG. 5–Taper of the butt logs at age 7 years after planting

to 200 stems/ha from the initial stocking of 400 stems/ha was carried out to examine the effects of the following as thinning criteria:

(a) butt log straightness;
(b) mean tree height;
(c) mean dbh (Fig. 6).

Effect of butt log straightness as a selection criterion

If crop trees were first selected on butt log straightness, cuttings (89%) had a significantly higher percentage of straight (sweep <6 mm/m) butt logs than seedlings (31%) (Fig. 6a). The cuttings were also taller than the seedlings (means of 11 m and 10.5 m, respectively) (Fig. 6b). However, the mean dbhob of the cuttings (24.4 cm) was significantly less compared than that of the seedlings (25.2 cm) (Fig. 6c).

Effect of height as a selection criterion

If crop trees were first selected on height, cuttings (74%) would have a significantly higher percentage of straight butt logs than seedlings (30%) (Fig. 6a). The cuttings were again significantly taller than the seedlings (means of 11.2 m and 10.5 m, respectively) (Fig. 6b). However, there was no significant difference in mean dbh between cuttings and seedlings (24.9 cm and 25.3 cm, respectively) (Fig. 6c).

Effect of dbh as a selection criterion

If crop trees were first selected on dbh, cuttings still had a significantly higher percentage of straight butt logs compared with seedlings (69% *v.* 30%) (Fig. 6a). The cuttings were again significantly taller than the seedlings (11 m *v.* 10.5 m) (Fig. 6b) and again there was no significant difference in dbh between cuttings (25.3 cm) and seedlings (25.4 cm) (Fig. 6c).

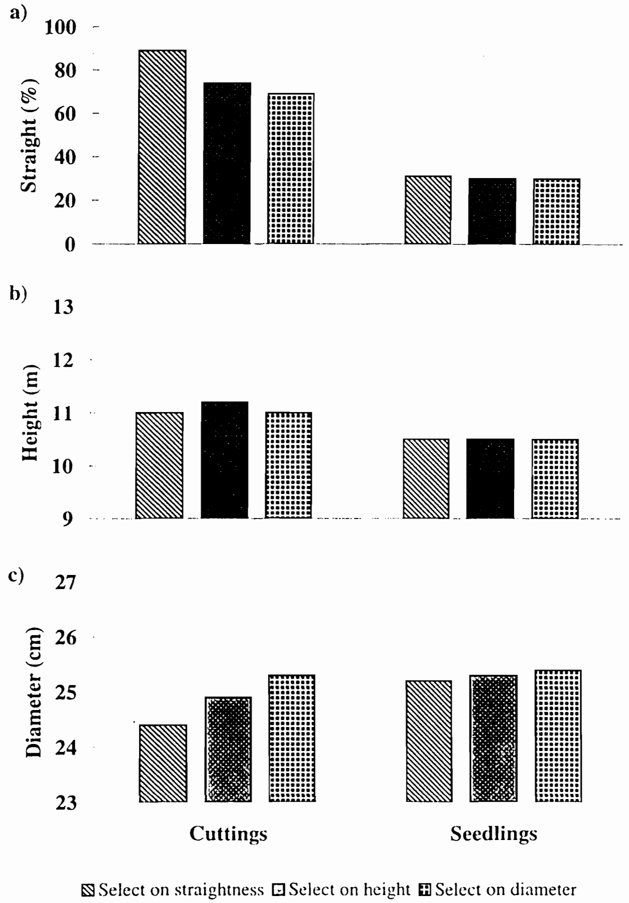

FIG. 6–Effect of selection criteria on (a) butt log straightness, (b) mean height, and (c) mean dbh.

Overall, it was apparent that if the first selection of the crop at final pruning was based on either height or dbh, the diameter of the crop might be similar for both cuttings and seedlings. If form was the first selection criterion, then the seedlings might have a slightly larger diameter. Cuttings had a significantly higher predicted percentage of straight butt logs compared with seedlings, regardless of which selection criterion was used. This overall trend was similar for initial stockings of both 200 and 600 stems/ha.

Growth and Yield Predictions Using PC-STANDPAK

GROSTAND inputs, growth, and pruned log outputs predicted at age 28 years are shown in Table 6.

Predicted growth was similar for both seedlings and cuttings although cuttings were taller and had a slightly larger total volume. The difference, however, was likely to be within the error limits of the model. Although cuttings were pruned slightly higher than seedlings, the log length (5.5 m) was kept constant for both types to avoid this having any additional effect on log value.

TABLE 6–GROSTAND inputs, growth, and pruned log outputs from PC-STANDPAK

	Seedlings	Cuttings
GROSTAND regime inputs		
Initial stocking (from first pruning) (stems/ha)	300	300
Prune to 40% height @ age 3.8 years (stems/ha)	300	300
Prune to leave 3.5 m green crown @ age 4.8 years (stems/ha)	300	300
Prune to 4.7 m @ age 5.9 years (stems/ha)	250	250
Thin to waste (least pruned) leaving (stems/ha)	250	250
Prune to 6.0 m @ age 6.9 years (stems/ha)	220	220
Thin to waste (least pruned) leaving (stems/ha)	220	220
Final stocking @ age 28 years (stems/ha)	206	206
Growth outputs		
Height (m)	40.3	41.2
Dbh (cm)	61.1	60.9
BA (m^3/ha)	60.3	59.9
Volume (m^3/ha)	794	805
Log outputs (pruned only)		
Log length (m)	5.5	5.5
Recoverable volume (m^3/ha)	209.3	223.3
Mean small-end diameter (mm)	475	474
Taper (mm/m)	16.3	16.1
Max. DOS (mm)	212	206
Max. branch (mm)	63	58
Max. defect core (mm)	289	273
Mean defect core (mm)	247	221

Diameter over stubs (DOS) and maximum branch diameter (max. branch) measurements were not collected, but predicted values were similar to actual values from two trials in the 1984 series at Tikitere and Kanui Station, where identical stock types were grown on similar sites. The smaller predicted DOS and max. branch, combined with less sweep, resulted in a smaller predicted defect core (DC) in the cuttings and produced a higher recoverable volume for cuttings (223 m^3/ha) than for seedlings (209 m^3/ha). It is important to note that some logs were rejected because of extreme sweep.

The predicted pruned log timber grade outturn is shown in Table 7. Cuttings had a higher percentage (57%) of No. 1 and 2 clears predicted than the seedlings (53%). Percentages of all other grades were slightly higher in the seedlings. Total predicted sawn volume was higher for cuttings (126 m^3/ha) than for seedlings (113 m^3/ha) and most of the extra volume in the cuttings was sawn as No. 1 and 2 clear grade timber.

TABLE 7–Predicted log timber grade outturn

Grade	Seedlings		Cuttings	
	Percentage	m^3 sawn/ha	Percentage	m^3 sawn/ha
No. 1 & 2 clears	53.0	59.8	57.0	71.5
No. 1 cuttings and Factory	4.0	4.5	3.9	4.9
No. 1 & 2 Framing	33.1	37.3	31.5	39.5
Box	9.9	11.2	7.7	9.6
Total recovery	53.9	112.8	56.2	125.5

Predicted Residual Pruned Log Value

The predicted residual log value (RLV) is the value of the logs to the processor delivered at mill as defined by:

RVL = value of output at processing plant – (production costs + allowance for return on capital)

Results are shown in Table 8.

TABLE 8–Predicted residual pruned log value

	Seedlings	Cuttings
Residual value ($/m³ log) at mill	133	150
Residual value ($/ha) at mill	27,837	33,495

On a pruned log basis, the cuttings had a higher predicted residual value ($150/m³) than the seedlings ($133/m³). The higher predicted recoverable volume per hectare for cuttings contributed to a total predicted residual value per hectare of $33,495 for cuttings compared with $27,837 for seedlings. These differences are considerable and likely to be outside the error limits of the STANDPAK model (P. Maclaren pers. comm.). These predicted residual values are not stumpage values and should be used for comparative purposes only, not for defining absolute levels of profitability.

DISCUSSION

During the last two decades large-scale plantations using rooted cuttings from improved trees have been established for *P. radiata* (Clarke & Slee 1984; Arnold & Gleed 1985; Wilcox 1988), *Picea abies* (L.) Karsten (Norway spruce) (Kleinschmit 1974; Bentzer 1981), *P. mariana* (Mill.) B.S.P. (black spruce) (Armson *et al.* 1980), and *Chamaecyparis nootkatensis* (D.Don) Spach (yellow cypress) (Karlsson 1981; Karlsson & Russell 1990).

Ortet age plays a major role in rooting ability, stem form, branching habit, taper, and growth of *Pinus radiata* trees originating from cuttings. All these characteristics can influence the cost and economic gain of plantation forestry. The ortet age of 3 years is regarded as optimum because the cuttings show highly acceptable rooting percentages of about 80% (Thulin & Faulds 1968) as well as other advantageous characteristics such as fewer leader and stem defects and less toppling, without loss of growth, than seedlings of similar genetic origin (Klomp & Menzies 1988; Menzies & Klomp 1988; Menzies *et al.* 1991). At this ortet age, bark thickness of cuttings tends to be similar to that of seedlings, particularly in young stands (Menzies & Klomp 1988), and so bark thickness is unlikely to influence under-bark diameter or differences in taper.

In addition to the Valley Road trial reported here, *P. radiata* cutting/seedling comparisons were established on 10 other North Island sites in this trial series in 1984. In the Valley Road trial, the cuttings had significantly better height growth than the seedlings at 7 years after planting and this trend was apparent on two other farm sites (Appendix 2). In general, cuttings from 3-year-old donor trees grew as tall as or taller than the seedlings on all 11 sites. The cuttings had a smaller dbh at Valley Road and one other site, a forest (sand-dune) site at Pouto, but on the nine other sites cuttings showed minimal loss in dbh compared with seedlings.

The reason for the slight loss in dbh growth for the cuttings at Valley Road was most likely their superior survival rate and form which resulted in a higher proportion of the smaller trees being retained than among the seedlings. This was supported by the simulated thinning exercise (Fig. 6) where the difference in dbh disappeared when the crop element was first selected on height or dbh.

The initial stocking had some influence on the growth of both stock types. Cuttings and seedlings were significantly taller in plots at higher initial stockings, but there was no significant difference in dbh among the three stockings. This suggests that both stock types benefited from mutual protection and this was expressed in improved height growth. The lack of differences in dbh for the different levels of initial stocking is unusual as differences have been observed in most stocking trials (P. Maclaren pers. comm.). However, the early thinning (age 3.5 years) in this trial may have counteracted any apparent stocking effect.

Considerable early toppling in the seedling crop caused significantly lower survival than with the cuttings at Valley Road 7 years after planting. This trend occurred on two other sites in the trial series, whilst on eight other sites the difference was not significant.

At Valley Road, the superior straightness of the cuttings was obvious at the early visual assessments after the pruning lifts and this was verified by the actual measurements of butt log sweep after the fourth lift. Visual assessments of form carried out at the other 10 sites revealed a similar trend.

Regardless of whether crop selections were based on height, dbh, or straightness, the cuttings consistently had a significantly higher percentage of straight logs. Crop selection ratios at Valley Road indicated that, to achieve a crop quality similar to cuttings, at least double the number of seedlings needed to be planted. This trend was also evident in seedling/cutting comparisons on other sites (Menzies *et al.* 1991).

The cuttings had less taper in the butt log than the seedlings 7 years after planting. The effect of this reduced taper is difficult to evaluate as little is known of the relationship between juvenile and mature log taper. Adjusted taper values were tested as inputs into SAWMOD, but had little effect on either grade outturn or log value predicted at age 28 years. Bark thickness could affect log taper and log volume, particularly in older trees, but is unlikely to have affected the results in this trial with cuttings from 3-year-old ortets measured at age 7 years (Menzies & Klomp 1988).

Generally, the model predicted early growth equally well for seedlings and cuttings. However, the basal area growth on this site was higher than the maximum level available in the growth model EARLY and there is need for modification of the model to cater for these high fertility sites. After an adjustment to the initial basal area, there is reasonable confidence that the predicted log volume at age 28 years is accurate (Maclaren 1993).

Although PC-STANDPAK predicted a slightly higher recoverable volume from the cuttings than from the seedlings (because of logs rejected due to severe sweep), this had little or no effect on the residual log value. The major factors responsible for the greater outturn of clear grade timber and higher value in the cuttings were the straightness of the pruned log and the smaller defect core. Spencer (1987) also stressed that the higher quantity of clear wood derived from rooted cuttings is mainly attributable to their superior form.

CONCLUSIONS

At the Valley Road trial, the cuttings from 3-year-old ortets clearly demonstrated advantageous characteristics such as less malformation and superior stem straightness, compared with seedlings of equivalent genetic quality. On the basis of STANDPAK analysis, it is predicted that the planting of physiologically-aged cuttings from 3-year-old donor trees will result in a substantial increase in the quality of sawlogs grown on a fertile site. The predicted value of clear grade timber from pruned logs of the cuttings was 20% higher than from the seedlings.

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APPENDIX I

PC-STANDPAK (Whiteside 1990) INPUTS USED IN THE ECONOMIC EVALUATION OF CUTTINGS AND SEEDLINGS

	Seedlings/Cuttings
Growth models	EARLY and NAPIRAD
Height model	KGM3 (34)
Stand volume table	KGM3 (29)
Basal area level	High + 20%
Weibull equation	Rotorua Conservancy
Taper equation	Kaingaroa Young Crop
Breakage equation	Kaingaroa Young Crop
Density class	Medium
Sweep class	*see below*
Internode levels	Medium
Clear felling age	28 years
Sawmill type	Carriage Bandmill A
Conversion standard	2
Sawmill uptime	90%
Timber price list	Domestic (1988)

Mean sweep in pruned log

	Seedlings	Cuttings
Juvenile sweep (mm/m) (for LOGASORT)	13.9	5.3
Mature sweep (for SAWMOD)		
Mean sweep 0–6 mm/m	3.4	1.6
Mean sweep > 6 mm/m	11.6	8.7
Percentage swept 0–6 mm/m	30.0	70.7
Percentage swept > 6 mm/m	70.0	29.3

APPENDIX 2

GROWTH COMPARISONS AT AGE 7 YEARS AT 11 SITES

Sites	Height (m)			Dbh (cm)			Survival (%)		
	S	C	Signif.	S	C	Signif.	S	C	Signif.
Farm									
Valley Road	10.1	10.7	*	25.7	24.6	*	47	65	*
Whangarei	9.8	10.7	*	17.9	18.0	ns	58	82	ns
Tikitere	9.1	9.5	ns	23.2	22.4	ns	20	62	*
Reporoa	9.3	9.6	ns	21.0	20.6	ns	56	67	ns
Kanui Station	8.3	8.7	*	21.8	21.5	ns	52	65	*
Oroua Downs	7.9	8.0	ns	17.7	17.8	ns	79	81	ns
Forest									
Otangaroa	8.8	9.0	ns	15.0	14.3	ns	41	55	ns
Pouto	9.5	9.4	ns	17.8	16.8	*	90	88	ns
Rerewhakaaitu	8.0	8.3	ns	17.0	16.3	ns	60	81	*
Taupo	9.6	9.9	ns	20.6	20.3	ns	61	75	ns
Tahorakuri	9.6	9.7	ns	19.7	19.2	ns	75	71	ns

* Difference significant at p = 0.05
S Seedlings, special "268" selection
C Cuttings, from 3-year-old donor trees, "268" × "875" selection
Note: Survival was affected by a scheduled thinning at Valley Road. All sites experienced periodic cull thinnings for topples, runts, and blown tops.