ESTABLISHMENT REQUIREMENTS OF PINUS RADIATA CUTTINGS AND SEEDLINGS COMPARED

G. G. WEST

Forest Research Institute, New Zealand Forest Service,
Private Bag, Rotorua, New Zealand

(Received for publication 28 October 1983; revision 23 January 1984)

ABSTRACT

On three pasture sites at Putaruru, Rotorua, and Taradale, and on one forest site at Kaingaroa, the establishment requirements of **Pinus radiata** D. Don cuttings were found to be similar to those of seedlings. The removal of grass competition for a minimum of 1 year improved height growth of both cuttings and seedlings at age 5 by an average of 1.7 m (30% improvement) and diameter growth by an average of 3.2 cm (32% improvement) (equivalent to 1 year's growth). Grass release for 2 years gave no significant increase in growth and would not justify the additional cost, even on drier sites. Only at Kaingaroa did the application of fertiliser at establishment result in some improvement in growth of both stock types.

Although by age 5 the cuttings and seedlings had shown similar height growth, the diameter growth of the seedlings was found to be 1.0 to 2.4 cm better than the cuttings, depending on site but not establishment treatment. The rapid diameter growth recorded on the farm sites in this study indicates the advantage of growing trees on sites with a history of pastoral farming.

INTRODUCTION

The use of superior selected individuals in genetic improvement programmes is a well-recognised method of increasing forest productivity (Thulin 1957). The current breeding programme for *Pinus radiata* in New Zealand has led to the production of improved seed from orchards of selected clones, and trees from such seed have shown an improvement in form which indicates that a reduction in initial stocking is possible (James 1979).

An alternative propagation method is to use rooted cuttings to multiply genetically improved seedlings, produced from seed orchards or by controlled pollination. The case for planting cuttings rather than seedlings has been widely discussed (Fielding 1964, 1970; Thulin & Faulds 1968; Libby *et al.* 1972), and a number of studies have compared the growth of the two tree-stock types. Sweet & Wells (1974) reported that cuttings had a lower relative growth rate than seedlings, and that the rate of growth of the cuttihgs declined with increasing physiological age. Shelbourne & Thulin (1974) also indicated that cuttings have a lower growth potential than seedlings. Menzies & Chavasse (1982) reported the same conclusions on hard sites. However, others (Fielding 1970;

Tufour 1974; B. K. Klomp pers. comm.) have found little growth difference between routine (unimproved) seedlings and cuttings taken from young trees.

Studies comparing form, branching, and other morphological characteristics between cuttings and seedlings indicate that cuttings have the advantages of fewer and smaller branches, and less stem taper (Fielding 1970; Pawsey 1971; Tufour & Libby 1973; Tufour 1974). However, cuttings are more likely to be browsed (Pawsey 1950; Fielding 1970; Wells 1974; Klomp pers. comm.) and, depending on the age of the parent material, could have earlier and more abundant stem cones.

In the future, if cuttings can be produced on a commercial scale with better morphological characteristics than those of the present seed orchard seedlings, a reduction in silvicultural costs could be achieved. On some fertile pasture sites where poor form and large branches have been experienced with seedlings and where reducing the smothering effect of pruning and thinning slash on understorey pasture is of importance, this form of propagation may be of special benefit. However, indications from several field trials show that the growth of cuttings may be considerably affected by grass competition. Many studies with seedlings have shown a considerable improvement in growth rate with the removal of grass competition (de Boer 1970; Davenhill 1971; Forest Research Institute 1974, 1982; Knowles & Klomp 1975; McKinnell 1975; Squire 1977; Cellier & Stephens 1980; Brunsden 1980), although on a high-rainfall site first-year results of one study showed little improvement from grass release (Beveridge & Klomp 1973).

The application of fertiliser at establishment has been noted to improve the growth of seedlings on some sites (de Boer 1970; Squire 1977; Ballard 1978; Cellier & Stephens 1980), but similar trials have not been carried out with cuttings. A study was undertaken to compare the early growth and survival of cuttings on grass sites (including pasture weeds and legumes) with the performance of seedlings. Although the cuttings were "bulk collected" and not from genetically improved stock, it was considered that they should indicate the establishment requirements of future vegetatively propagated clonal material.

METHODS

Location of Trial Areas

Four trials were carried out on different types of site. Rainfall figures given below are averages for the years 1977 to 1981, recorded at the nearest meteorological station. Each station was within 22 km of the trial site.

Putaruru: A fertile, flat, farm site in the Ngatira district, with well-developed pasture, grazed until the time of planting. Average rainfall 1470 mm.

Rotorua: A flat *Pinus nigra* subsp. *laricio* (Poir.) Maire (Corsican pine) cutover adjacent to the Forest Research Institute nursery; it was stumped, root raked, cultivated, and sown in a mixture of grasses in spring 1976, approximately 1 year before tree planting. Average rainfall 1371 mm.

Taradale: A hill-country farm site (Rotokare), 8 km west of Taradale, exposed hillside (26° slope), with a northerly aspect, and grazed until the time of planting. Average rainfall 884 mm.

Kaingaroa: A *P. radiata* cutover (Cpt 37), slightly sloping, on pumice soils. No grass competition. Average rainfall 1465 mm.

Planting Stock

The seedlings were 1/0 seed orchard stock and the cuttings were 0/1 bulk collected from a 4-year-old plantation (not of seed orchard origin) in Kaingaroa State Forest. Both the seedlings and the cuttings were raised in the FRI nursery. The trials were hand planted in August 1977 using the cross-notch (+) method.

Treatments

Not all treatments were examined at all sites (Table 1). Treatments 1–5 were repeated on the three pasture sites at Putaruru, Rotorua, and Taradale, but only Treatments 2 and 5 were studied at Kaingaroa. It is current practice at Kaingaroa Forest to apply a post-planting spray of herbicide to reduce frost damage. It was therefore impractical to examine the effects of grass competition at this site. Treatments 7 and 8, involving added fertiliser and no competition for 4 years, were examined at the Rotorua site only. A caragard/paraquat mixture (4 kg caragard + 6 *l* paraquat per sprayed hectare) was used for the initial pre-planting pasture kill. Later treatments were with caragard or amitrole and caragard. The area was treated by spraying spots 1 m in diameter or strips 1 m wide, depending on the site. The two fertilisers were applied in separate spade notches, 15 cm from the stem, on opposite sides of the tree and, on hilly terrain, located across the slope. In Treatments 7 and 8, which involved repeated applications, the fertiliser was placed at the edge of the tree crown in the second and third years and in the fourth year it was broadcast.

Trial Layout

A randomised complete block design was used at each site, with each treatment plot consisting of 10 cuttings and 10 seedlings in four rows of five trees. The cuttings and seedlings were planted in alternate rows. The number of replicates and the tree spacing are given in Table 2.

To separate plots at the Putaruru trial, 2-m buffers (along the rows) were planted with similar tree stocks; at the Rotorua site 2-m buffers were left unplanted between plots. The wider spacing of trees at the other two sites was considered to give sufficient distance between treatments so that no buffers were required.

Measurements and Data Analysis

The heights of all trees were measured immediately after planting (August 1977) and then annually in July. Survival was also recorded at each of these measurements. Diameters at breast height over bark were measured on all trees in 1981 and 1982 (ages 4 and 5 years).

The data from each site were analysed separately as a randomised complete block design with split plots (for the cutting/seedling comparison) using the GENSTAT statistical package (IBM 1966). Although at the time of planting the cuttings were 7 cm taller on average than the seedlings, no significant evidence was found for

TABLE 1—Treatment details

Treatment	Description	Location
1. Grass competition (control)	Trees planted directly into the untreated grass sward	Putaruru Rotorua Taradale
2. No grass competition for 1 year	Pre-planting kill of pasture with repeated applications of herbicide to prevent competition for 1 year.	Putaruru Rotorua Taradale Kaingaroa
3. No grass competition for 2 years	Herbicide application as in Treatment 2, with repeated applications to give 2 years with no grass competition.	Putaruru Rotorua Taradale
4. Grass competition + fertiliser	Trees planted directly into grass sward, with 56 g urea + 170 g potassic (30%) superphosphate applied 2 months after planting.	Putaruru Rotorua Taradale
5. No grass competition for 1 year + fertiliser	Herbicide application as for Treatment 2, with fertiliser application as in Treatment 4.	Putaruru Rotorua Taradale Kaingaroa
6. No grass competition for 4 months	The normal preplanting spray of herbicides to give approximately 4 months of no grass competition.	Putaruru
7. Grass competition + fertiliser for 4 years	As in Treatment 4, with applications of the same fertiliser mixture approximately every 6 months for the first 4 years.*	Rotorua
8. No grass competition + fertiliser for 4 years	Herbicide application to give 4 years with no grass competition and fertiliser applied as in Treatment 7.	Rotorua

* Six applications were made at the rate given in Treatment 4 – two in the first year (Oct and May), two in the second year (Oct and May), one in the third year (Nov), and one in the four year (Oct).

TABLE 2—Replication and spacing

Site	Replicates	Spacing (m)
Putaruru	7	7 × 2
Rotorua	6	1.5 × 1.5
Taradale	5	3 × 3
Kaingaroa	4	3 × 3

covariance adjustment of increment. To normalise the distribution of the survival percentages, arc sine transformation was undertaken prior to analysis of variance. All SNK tests were made at the 5% significance level.

RESULTS

Survival

Five years after planting, the over-all survival of the cuttings was similar to that of the seedlings at all sites (Table 3).

TABLE 3—Mean tree survival, height increment, and d.b.h. at age 5 years (all treatments)

Site	Cuttings	Seedlings	Difference
Tree survival (%)			
Putaruru	89.5	87.6	(1.9) ns
Rotorua	77.6	79.9	(2.3) ns
Taradale	74.0	71.0	(3.0) ns
Kaingaroa	89.0	95.0	(6.0) ns
5-year height increment (m)			
Putaruru	6.49	6.73	(0.24) **
Rotorua	7.10	7.28	(0.18) *
Taradale	6.22	6.12	(0.10) ns
Kaingaroa	5.26	5.43	(0.17) ns
Diameter (d.b.h.) at age 5 years (cm)			
Putaruru	12.45	14.84	(2.39) **
Rotorua	9.97	12.14	(2.17) **
Taradale	10.53	12.31	(1.78) **
Kaingaroa	8.23	9.19	(0.96) *

ns = not significant
* = significant at p = 0.05
** = significant at p = 0.01

Although only at Putaruru a cutting/seedling × main treatment interaction was found to be significant (Table 4), this effect was considered to be very marginal, and so to simplify examination of treatment effects, the cuttings and seedlings data were combined for testing between treatments. Differences between treatments indicate that, except at the Rotorua site, grass competition had considerably reduced survival (Table 5). At the Taradale site (Fig. 1) survival was only 45% with grass competition present compared with 97% with grass competition removed. The application of fertiliser in the presence of grass competition reduced tree survival at both Putaruru and Taradale. On all sites there were no significant differences between the tree survivals with treatments involving some removal of grass competition (Treatments 2, 3, 5, and 6), with or without fertiliser.

FIG. 1—Tree survival at Taradale trial at age 2 years. For explanation of treatment numbers, see Table 1. Treatments 1 and 4 involve no removal of grass competition.

TABLE 4—Analysis of variance - survival, height increment, and d.b.h.

	Putaruru	Rotorua	Taradale	Kaingaroa
Survival at age 5 years				
Replicates	ns	ns	ns	ns
Main treatments	**	ns	**	ns
Cuttings/Seedlings	ns	ns	ns	ns
Cuttings/Seedlings × Main treatments	*	ns	ns	ns
5-year height increment				
Replicates	ns	ns	ns	**
Main treatments	**	**	**	**
Cuttings/Seedlings	**	*	ns	ns
Cuttings/Seedlings × Main treatments	ns	ns	ns	ns
Diameter (d.b.h.) at age 5 years				
Replicates	ns	ns	**	ns
Main treatments	**	**	**	*
Cuttings/Seedlings	**	**	**	*
Cuttings/Seedlings × Main treatments	ns	ns	ns	ns

ns = not significant
* = significant at p = 0.05
** = significant at p = 0.01

TABLE 5—Effects of grass competition and fertiliser treatments on survival, height increment, and d.b.h. by age 5 (SNK tests use means of both the seedlings and the cuttings)

Putaruru		Rotorua		Taradale		Kaingaroa	
Survival at age 5 (%)							
3*	100 a†	2	96 a	2	98 a	5	92 a
2	99 a	5	95 a	3	97 a	2	91 a
5	96 a	7	94 a	5	97 a		
6	95 a	4	93 a	1	45 b		
1	78 b	3	93 a	4	23 c		
4	63 c	1	92 a				
		8	89 a				
5-year height increment (m)							
5	7.73 a	5	7.94 a	3	7.41 a	5	5.62 a
3	7.64 a	8	7.72 ab	5	6.76 a	2	5.07 a
2	7.48 a	2	7.53 ab	2	6.74 a		
6	5.93 b	3	7.47 ab	1	5.26 b		
4	5.58 b	7	6.90 bc	4	4.70 b		
1	5.33 b	4	6.56 c				
		1	6.20 c				
Diameter (d.b.h.) at age 5 (cm)							
5	16.3 a	8	12.5 a	3	13.4 a	5	9.4 a
3	16.0 a	5	12.1 a	2	12.6 a	2	8.0 b
2	15.3 a	2	11.7 ab	5	12.4 a		
6	11.8 b	3	11.6 ab	1	9.6 b		
4	11.6 b	7	10.8 b	4	9.1 b		
1	10.8 b	4	9.6 c				
		1	9.1 c				

* Treatment numbers – refer to Table 1.
† Values with the same letter are not significantly different ($p = 0.05$)

Height Growth

The height growth of the seedlings was significantly better than that of the cuttings at Putaruru and Rotorua but showed no significant differences at Kaingaroa and Taradale (Table 3). As there was not a significant cuttings/seedlings × main treatment interaction (for height growth or d.b.h. at age 5), the cutting and seedling data were combined to test for differences between treatments.

On all sites the removal of grass competition for at least 1 year (Treatments 2, 3, 5, 8), resulted in significantly improved height growth (Table 5). However, at Putaruru when grass release was only for 4 months (Treatment 6) the improvement was very slight and statistically not different from Treatment 1 with no grass release. Two years of grass release (Treatment 3), rather than 1 year (Treatment 2), gave no significant improvement in height growth. The application of fertiliser, with and without grass competition, had no significant effect on height growth even when repeated for 4 years (Treatments 7 and 8).

Age 5 d.b.h.

At all trial sites the mean d.b.h. of the seedlings at age 5 was significantly greater than that of the cuttings (Table 3). Grass release for at least 1 year resulted in a significant improvement in diameter growth (Table 5) but, except at Kaingaroa and Treatment 7 at Rotorua, the application of fertiliser did not have a significant effect. The single application of fertiliser at Kaingaroa resulted in a 1.4-cm improvement in d.b.h. (mean of both stock types); the multiple applications at Rotorua significantly improved diameter growth where grass competition remained (Treatment 7) but not where grass competition was removed (Treatment 8).

Height Variability

The effect of treatment on height variability (as quantified by the within-plot standard deviation) was examined at the Putaruru and Kaingaroa sites (because of the close spacing (1.5 × 1.5 m) at Rotorua and the poor survival at Taradale, these trials were not considered suitable for this analysis). Within-plot variability in height for the cuttings and the seedlings was not significantly different, so the data were combined. Treatments that involved at least 1 year free from grass competition (Treatments 2, 3, 5) were less variable than those that did not (Table 6). The application of fertiliser at establishment did not decrease height variability on these sites.

TABLE 6—Effect of treatment on height variation at age 5 (SNK test, within-plot means, cuttings and seedlings combined)

Putaruru			Kaingaroa		
Treatment No.	Standard deviation	Coefficient of variation	Treatment No.	Standard deviation	Coefficient of variation
1	1.43 a	25.4	2	1.0 a	18.7
4	1.29 a	22.0	5	0.9 a	15.2
6	1.21 a	19.4			
2	0.86 b	11.0			
5	0.83 b	10.3			
3	0.83 b	10.4			

Values with the same letter are not significantly different ($p = 0.05$)

DISCUSSION

Five years after planting, grass competition from well-established pasture had considerably reduced survival in both the cuttings and the seedlings, particularly at the drier site at Taradale. At Putaruru some losses resulting from grass smothering (not root competition) in the control treatments may not have occurred with larger tree stocks. Knowles & Klomp (1975) found that, given adequate rainfall, survival of sturdy 1½/0 seedlings was good even without grass release. The recently established grass sward at the Rotorua trial appeared to affect tree survival far less than a fully established pasture such as at Putaruru, but it still seriously affected tree growth over the 5-year period.

Over-all, the difference in height growth of seedlings and cuttings was less than 0.3 m (Fig. 2). However, the diameter growth of the seedlings was considerably greater than that of the cuttings – a difference of 0.96 to 2.39 cm at age 5, depending on site. The difference in height growth is of little practical importance, but the diameter differences may have greater consequences for the future profitability of plantations established from cuttings. In stands that are pruned, the smaller d.b.h. of cuttings is expected to result in a smaller DOS (diameter over pruned stubs, Knowles *et al.* in prep.) and this may compensate for some reduction in final tree diameter. The difference in diameter growth of the two tree-stock types appears to be influenced by site quality, with the greatest difference on the fertile site at Putaruru and the least at Kaingaroa.

FIG. 2—Seedlings/Cuttings comparison. Putaruru trial at age 3 years - seedlings left, cuttings right.

The effect of grass competition on growth was found to be the same for cuttings as it was for seedlings, release treatments giving considerable improvement in height and diameter growth. The small improvement with only 4 months' grass release compared with the result of 1 year's grass release (Table 5), emphasises the importance of removing grass competition for the first full growing season (through to April). Although good survival is achieved with 4 months' grass release, height and diameter growth are virtually unimproved (Table 5). When grass competition was removed for a minimum of 1 year, height growth at age 5 was improved by an average of 1.7 m (30%) and diameter growth by an average of 3.2 cm (32%), depending on site and tree-stock type – an improvement in growth equivalent to at least 1 year's growth. This result is similar to that achieved in comparable studies by others using seedlings (Forest Research Institute 1974, 1982; de Boer 1970; Davenhill 1971; Knowles & Klomp 1975; McKinnell 1975). However, the fact that the major improvement in height growth from grass release was not evident until the second year indicates the inadequacy of making comparisons using only first-year data. Grass release continued to improve height growth through to the end of Year 3 at Taradale and Year 4 at Putaruru and Rotorua (Table 7). The 2 years of grass removal gave no significant improvement in growth over 1 year of grass removal and would not justify the additional cost, even on the drier Taradale site.

Pasture composition differed markedly at Putaruru and Taradale. Without grazing, the deep-rooted species at both sites (ratstail (*Sporobolus africanus* Poir.) at Taradale, and cocksfoot (*Dactylis glomerata* L.) at Putaruru) predominated. However, differences

TABLE 7—Analysis of variance – annual height increment

Site	Year	Treatments	Cuttings/Seedlings	Cuttings/Seedlings × Main treatments
Putaruru	1	**	**	**
	2	**	**	ns
	3	**	**	ns
	4	**	ns	ns
	5	ns	ns	ns
Rotorua	1	**	**	ns
	2	**	ns	ns
	3	**	**	ns
	4	*	*	ns
	5	ns	ns	ns
Taradale	1	**	**	**
	2	**	*	**
	3	**	ns	*
	4	ns	ns	ns
	5	ns	ns	ns
Kaingaroa	1	*	**	ns
	2	ns	ns	ns
	3	ns	ns	ns
	4	ns	ns	ns
	5	ns	ns	ns

ns = not significant

* = significant at p = 0.05

** = significant at p = 0.01

in rainfall and soil fertility are likely to be of greater importance. The single application of fertiliser, with or without grass release, gave a significant improvement in growth only at the Kaingaroa site (Table 5). At Putaruru and Taradale (Taradale not significant at $p = 0.05$) the application of fertiliser without grass release reduced both tree survival and growth, indicating the encouragement of grass competition. A similar result has been reported by Waring (1972) and Squire (1977). Compared to the single application, multiple applications of fertiliser at Rotorua gave a slight improvement in growth with grass competition but not when grass competition was removed. This result is thought to be an anomaly and may be due to the effect of herbicide.

The reduction of tree height variability in Treatments 2, 3, and 5 indicates that grass control that is effective for at least 1 year may reduce problems of crop variability during the early tending phase. The rapid diameter growth recorded on the farm sites (Putaruru and Taradale) in this trial is consistent with previous studies (Skinner & Attiwill 1981; West *et al.* 1982) and indicates the advantages of growing trees on sites with a history of pastoral farming.

ACKNOWLEDGMENTS

I am grateful to members of the Exotic Forest Management section who have given advice and assisted with the establishment and measurement of this study: to M. Kimberley for the statistical analysis of data; to the officers of Ellis and Burnand Ltd (now Tasman Forestry Ltd); to G. Williams (Rotokare); to I. McQueen and J. Bilkey (Ministry of Agriculture and Fisheries); and to R. L. Knowles, C. J. A. Shelbourne, M. I. Menzies, I. R. Hunter, and R. O. Squire for their comments during preparation of the report.

REFERENCES

BALLARD, R. 1978: Use of fertiliser at establishment of exotic forest plantations in New Zealand. **New Zealand Journal of Forestry Science 8:** 70–104.

BEVERIDGE, A. E.; KLOMP, B. K. 1973: Tolerance of **Pinus radiata** to grass competition. **New Zealand Journal of Forestry 18(1):** 148–51.

BRUNSDEN, G. J. 1980: Growth responses and stability of radiata pine to chemical weed control and ripping in pumice pasture land. **Proceedings of the 33rd New Zealand Weed and Pest Control Conference:** 181–5.

CELLIER, K. M.; STEPHENS, C. G. 1980: Effect of weed control and fertiliser placement on the establishment and early growth of **Pinus radiata** in Southern Australia. **Australian Forest Research 10:** 361–9.

DAVENHILL, N. A. 1971: Tree release from grass. **Proceedings of the 24th New Zealand Weed and Pest Control Conference:** 38–42.

de BOER, D. 1970: Chemical release of **Pinus radiata** in grasslands. **Appita 23:** 291–8.

FIELDING, J. M. 1964: The possibility of using cuttings for the establishment of commercial plantations of Monterey pine. **Proceedings of FAO World Constitution on Forest Genetics and Tree Improvement, Stockholm, Vol. 11:** 5/10.

——— 1970: Trees grown from cuttings compared with trees grown from seed (**Pinus radiata**). **Silvae Genetica 19:** 54–63.

FOREST RESEARCH INSTITUTE 1974: New success in establishing trees on pasture. **New Zealand Forest Service, Forest Research Institute, What's New in Forest Research No. 11.**

——— 1982: Grass control. **New Zealand Forest Service, Forest Research Institute, What's New in Forest Research No. 113.**

IBM 1966: "System/360 Scientific Subroutine Package (360-CM-03X) Version 111." International Business Machines, White Plains, New York.

JAMES, R. N. 1979: The influence of tree breeding and stocking rate on tree crop quality. **New Zealand Journal of Forestry 24(2):** 230–40.

KNOWLES, R. L.; KLOMP, B. K. 1975: The use of chemicals to aid establishment of radiata pine on pasture. Pp. 153–7 **in** Chavasse, C. G. R. (Comp.) "The Use of Herbicides in Forestry in New Zealand". **New Zealand Forest Service, Forest Research Institute Symposium 18.**

KNOWLES, R. L.; WEST, G. G.; KOEHLER, A. R.: Predicting "Diameter-over-stubs" in pruned stands of radiata pine. **New Zealand Forest Service, FRI Bulletin** (in prep.).

LIBBY, W. J.; BROWN, A. G.; FIELDING, J. M. 1972: Effects of hedging radiata pine on production, rooting and early growth of cuttings. **New Zealand Journal of Forestry Science 2:** 263–83.

McKINNELL, F. H. 1975: Control of herbaceous weeds in Blackwood Valley pine plantations. **Forest Department of Western Australia, Research Paper No. 15.**

MENZIES, M. I.; CHAVASSE, C. G. R. 1982: Establishment trials on frost-prone sites. **New Zealand Journal of Forestry 27(1):** 33–49.

PAWSEY, C. K. 1950: Some observations upon the vegetative reproduction of Monterey pine. **Australian Forestry 14(2):** 90–4.

——— 1971: Comparisons of vegetatively-propagated and seedling trees of **Pinus radiata. Australian Forest Research 5(3):** 47–57.

SHELBOURNE, C. J. A.; THULIN, I. J. 1974: Early results from a clonal selection and testing programme with radiata pine. **New Zealand Journal of Forestry Science 4:** 387–98.

SKINNER, M. F.; ATTIWILL, P. M. 1981: The productivity of pine plantations in relation to previous land use. 1. Growth responses in agricultural and forest soils. **Plant and Soil 60:** 161–76.

SQUIRE, R. O. 1977: Interacting effects of grass competition, fertilising and cultivation on the early growth of **Pinus radiata** D. Don. **Australian Forest Research 7:** 247–52.

SWEET, G. B.; WELLS, L. G. 1974: Comparison of the growth of vegetative propagules and seedlings of **Pinus radiata. New Zealand Journal of Forestry Science 4:** 399–409.

THULIN, I. J. 1957: Application of tree breeding to New Zealand forestry. **New Zealand Forest Service, Forest Research Institute Technical Paper No. 22.**

THULIN, I. J.; FAULDS, T. 1968: The use of cuttings in the breeding and afforestation of **Pinus radiata. New Zealand Journal of Forestry 13(1):** 66–77.

TUFOUR, K. 1974: Comparative growth performance of seedlings and vegetative propagules of **Pinus radiata** and **Sequoia sempervirens.** Ph.D. Thesis, University of California, Berkeley.

TUFOUR, K.; LIBBY, W. J. 1973: First-lift pruning times of pine seedlings and rooted cuttings in a small California experiment. **New Zealand Journal of Forestry 18:** 124–32.

WARING, H. D. 1972: **Pinus radiata** and the nitrogen-phosphorus interaction. Pp. 144–61 **in** Boardman, R. (Ed.) "Proceedings of Australian Forest Tree Nutrition Conference 1971", Forest Timber Bureau, Australia.

WELLS, L. G. 1974: Differential browsing of **Pinus radiata** cuttings, grafts, and seedlings. **New Zealand Journal of Forestry 19(1):** 138–40.

WEST, G. G.; KNOWLES, R. L.; KOEHLER, A. R. 1982: Model to predict the effects of pruning and early thinning on the growth of radiata pine. **New Zealand Forest Service, FRI Bulletin No. 5.**