ESTABLISHMENT PRACTICES CAN IMPROVE LONGER-TERM GROWTH OF *PINUS RADIATA* ON A DRY-LAND HILL FOREST

J. M. BALNEAVES†, M. I. MENZIES, J. AIMERS-HALLIDAY, S. O. HONG

Forest Research Institute,
Private Bag 3020, Rotorua, New Zealand

A. R. McCORD, and R.J. McLAUGHLAN

Carter Holt Harvey Forests Ltd,
Private Bag 1002, Rangiora, New Zealand

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ABSTRACT

An establishment trial was planted on a dry-land hill forest site in the Okuku area of Ashley Forest, Canterbury, to compare the effects of seedling quality, handling, cultivation (ripping), and post-planting weed control on subsequent survival and growth of *Pinus radiata* D.Don up to 13 years after planting, i.e., at half-rotation. Weed control was the most significant factor, followed by seedling quality and cultivation (ripping). Lack of weed control, use of conventional seedling quality, and conventional handling resulted in a 43% loss of volume growth compared with the best treatment combination of weed control, "best practice" seedling quality, and "best practice" handling. Ripping was less important, but gave a 7% increase in volume.

Keywords: establishment; seedling quality; seedling handling; ripping; weed control; survival; growth; *Pinus radiata*.

INTRODUCTION

Forest establishment research in New Zealand came to the fore in the 1960s during the second major planting boom. Major research effort focused on seedling quality and nursery management practices, out-planting systems, and site amelioration, including land clearing, fire, cultivation, and chemical weed control. Other areas investigated included planting tools and methods, tree toppling, blanking (beating up), and site-specific problems such as frost-flat establishment.

Research effort in these areas culminated in a Symposium in 1981 (Chavasse 1981) and declined after this because it was considered that most of the research objectives had been attained and there was adequate information available to forest managers to ensure successful crop establishment.

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† Now deceased

Unfortunately, much of the research effort was of a short-term nature, with trials lasting only 2 to 5 years and with scant regard to the long-term influences of establishment practices on crop yield and profitability (Sollins *et al.* 1983; Dyck & Mees 1991). No effort was made to determine the economic viability of options under investigation. Furthermore, insufficient effort was made to integrate various aspects of establishment practices to develop workable "regimes" or to understand the influence one treatment might have on another. To address this, a single comprehensive trial was established at Ashley Forest in the North Canterbury region of New Zealand. The objective was to determine the interaction of seedling quality × tree handling systems × soil cultivation × weed control on the success of crop establishment and, more interestingly, on growth and yield at half-rotation (13 years).

METHODS

A trial was planted in a randomised complete block design with three blocks in the Okuku area of Ashley Forest. The site was located just below TrigK at 548 m a.s.l., and the topography was gentle to steep rolling land consisting of stony yellow-brown earths. Prior to acquisition for afforestation, the land was subjected to periodic burning of native tussock and grasses, oversown with introduced grass species, and topdressed, especially with superphosphate. Grazing was mainly with sheep, but beef cattle were used for summer grazing occasionally.

The soil was classed as nutritionally poor (by agricultural standards) with a relatively low pH (4.5–4.8). The site was harsh with very cold winters and snow lying on the ground for 4–6 weeks. However, warm Föhn winds in the spring soon dried the soils out and with hot dry winds over the summer months this site became very dry despite an annual mean rainfall of 1200–1500 mm during the 13-year trial period, with rainfall one year exceeding 1800 mm.

Plot Layout

Individual plots were 40 × 40 m with 200 trees per plot planted at 4 × 2 m spacing. By the time of final thinning, each plot contained 30 measurement trees within an internal plot of 30 × 30 m. This resulted in a final-crop stocking equivalent to approximately 350 stems/ha, with slight variation due to differences in mortality as a result of establishment treatments. The total area of the trial exceeded 8 ha and each of the three blocks was laid out to avoid site variations due to major geographical features.

The objectives were to examine the following effects both individually and in combination:

- Seedling quality (nursery treatments)
- Seedling handling (lifting/packaging/storage)
- Soil cultivation (ripping)
- Post-planting weed control.

Seedling Quality

Two batches of seedlings were raised for this trial from the one seed source (CY74/723/3) from the Amberley Seed Orchard.

Best practice seedlings

Seed was stratified for 2 weeks and then sown in drills 12.5 cm apart with 8 cm between seeds within drills. Each seedling, therefore, had 100 cm^2 growing space available. Any doubles or trebles per sowing space were thinned soon after emergence to leave only one seedling. Appropriate side dressings of fertiliser were applied and seedling beds kept free of weeds by judicious use of pre- and post-emergence weedicides. In mid-March, seedlings were undercut at 10 cm depth and root-wrenching occurred at 3-weekly intervals until lifting in the first week of July. Lateral-root pruning along the line of the drill took place 7 days after the initial undercut, and 3 weeks later between the seedlings within each drill. This was repeated at 6-weekly intervals until 1 week before lifting when lateral roots were once more pruned both along the line of the drill and between each seedling within the drill. This eliminated the need for root-trimming at lifting.

Conventional seedlings

Seed was soaked overnight and left to drain in a cool-store for 24 hours before sowing. Seed was sown through a conventional Stanhay Agricultural sower calibrated to sow seeds 5 cm apart within drills, with the drills being 12.5 cm apart. No post-emergence thinning occurred to reduce seedling density to one seedling per sowing space. Appropriate weed control practices and fertiliser amendments were applied. An initial undercut was done in mid-March and this was followed by three root wrenches. Lateral-root pruning, along the line of the drill only, was carried out at 6-weekly intervals commencing 3 weeks after the initial undercut.

Seedling Handling

Seedlings from each of the two seedling types were randomly divided into two groups and subjected to one of the following systems.

Best practice handling system

Seedlings were loosened in the soil prior to lifting. They were then handlifted and (as for the conventional seedlings) were root-trimmed so that the roots were no longer than 10 cm. The seedlings were then root-dipped in water, packed into DL-55 planting boxes, packed into the Trewin crate system (Trewin & Cullen 1985), cool-stored overnight, and then transported directly to the planting site and planted that day.

Conventional handling system

Seedlings were loosened in the soil prior to lifting. They were then handlifted and packed into wooden boxes for transport to a packaging shed 11 km from the nursery site. On arrival, the seedlings were hosed down and left overnight in the shed. The following morning, seedlings were counted into bundles of 25 and tied with rubber bands, and then root-trimmed to ensure that roots did not exceed 10 cm in length. All seedlings were root-dipped in water and packed upright into polythene bags (150 seedlings per bag) then packed upright into cardboard boxes (three bags per box). The boxed seedlings were cool-stored overnight before transporting to the forest. Seedlings were stored under a tarpaulin tent on the roadside in a shady situation for 96 hours before planting.

Soil Cultivation

Of the 16 plots in each block, eight were selected at random to be ripped to a depth of 70 cm using a wing-tined ripper mounted on a 4-wheel-drive tractor. This operation was carried out in late March, while the soil was dry, to ensure good soil shattering profile. The bouldery nature of the soil did cause some difficulty but in general the cultivation met expectations in that intensive soil probing showed that the depth of cultivation was greater than 60 cm and that the lateral extent of the cultivation was, on average, 39 cm either side of the centre of the ripped line. The other eight plots in each block were not cultivated.

Post-plant Weed Control

Eight plots in each block, including four plots that had been ripped and four uncultivated plots, were selected at random to be sprayed. Hexazinone in the WSP form was used at a rate of 2 kg/ha. This was applied with water in spots, 1-m diameter, over each tree within the plots in early spring (September), as ground vegetation was beginning to show signs of new growth after planting, and again 12 months later. The other eight plots in each block were not treated for weed control.

Planting

Planting of the trial was carried out by three gangs of 10 experienced planters (one gang per block) under very strict supervision. Each planter was allocated one row within each plot to plant and the allocation of planters to rows was random from plot to plot. Planting was by spade using the "positive-pull-up" technique (Trewin & Cullen 1985). Those trees packed on-bed into planting boxes were planted out directly from those boxes ("best practice" handling system). Those seedlings packed into plastic bags in the packing shed ("conventional" handling system) were taken from the cardboard cartons and the plastic bags were loaded two at a time by the planters into their canvas planting bags for planting out.

Assessments

Seedling height and diameter at ground line were measured, for all trees in each 40 × 40-m plot, 7 days after planting and then annually for 3 years. The trial was pruned and thinned on an Ashley Forest schedule, supervised by Forest Research Institute staff. The final thinning, which took place at age 8 years, lowered the stocking to a nominal 350 stems/ha. However, stocking levels varied slightly depending on the original mortality figures, which varied due to the different establishment treatments. At stand age 13 years the new forest owners, Carter Holt Harvey Forests Ltd, expressed an interest in the outcome of the trial and subsequently re-located, renumbered, and painted all the plot pegs. All trees were re-numbered and dbh bands marked. Total height and dbh (1.4 m above ground level) were measured on the trees within the internal 30 × 30-m plot.

Statistical Analysis

Analyses of variance (ANOVA) were based on a complete block design with a 2^4 factorial treatment structure. Data from the initial and age-3 assessments were analysed using ANOVA on the plot means for seedling height and diameter. For the age-3 data, survival was also analysed. For the age-13 data, ANOVA was carried out on plot means of dbh, height, and volume. A natural log transformation was carried out on the volume data in order to stabilise variances of treatments.

RESULTS AND DISCUSSION

Initial Results

The initial assessment, 7 days after planting, indicated that there was a significant difference in size of tree stocks between the "best practice" seedlings and the "conventional" seedlings. The "best practice" seedlings were significantly ($p \leq 0.05$) sturdier with a mean ground-line diameter of 5.7 mm and a mean height of 32 cm, while the conventional seedlings had a mean ground-line diameter of 4.3 mm and a mean height of 37 cm. There were no other differences as a result of the treatments at the outset of this trial.

Results for Age Three

Survival

Tree survival was greatly influenced by treatment (Table 1) and the differences were highly significant ($p \leq 0.01$) with the best treatment combination resulting in 93% survival and the worst only 18% survival. Seedling quality, handling, ripping, and weed control all had significant effects ($p \leq 0.01$) on survival, and many of the interaction terms were also highly significant (Table 2).

In previous work (Balneaves 1991; Balneaves & Menzies 1990; Balneaves *et al.* 1992), comparative studies of conventional handling systems and the improved FRI Handling System showed little response, if any, in seedling mortality. Rather, growth responses were affected. Similarly, survival was not affected by weed control and ripping treatments in a comparable *Pinus taeda* L. trial in eastern Oklahoma, but early growth responses were affected (Wittwer 1986). In the trial reported here, seedling handling did influence mortality,

TABLE 1–Effect of seedling quality, handling practice, ripping, and weed control on subsequent tree survival (%), mean height (cm), and mean dbh (cm) at age 3 years

Ripping	Weed control	Best practice handling		Conventional handling	
		Best practice seedling quality	Conventional seedling quality	Best practice seedling quality	Conventional seedling quality
Survival (%)					
+	+	93 a	73 c	63 d	40 fg
+	–	85 b	60 d	50 e	36 g
–	+	82 b	84 b	73 c	63 d
–	–	60 d	46 ef	41 fg	18 h
Tree height (cm)					
+	+	110 b	114 a	82 c	95 b
+	–	98 b	80 c	74 d	79 cd
–	+	89 bc	86 c	90 bc	80 cd
–	–	71 d	72 d	64 e	66 de
Tree dbh (cm)					
+	+	2.8 a	2.9 a	2.0 bcde	2.2 bc
+	–	2.4 b	1.7 cdef	1.6 ef	1.8 cdef
–	+	2.1 bcde	2.0 bcde	2.2 bcd	2.0 bcdef
–	–	1.6 def	1.6 def	1.3 f	1.4 f

Means followed by the same letter are not significantly different at the 5% level according to the least significant difference (LSD) test.

TABLE 2–Levels of significance for the analysis of variance at age 3 years

Treatment	Survival	Height	Diameter
Seedling quality	**	***	***
Handling system	**	ns	ns
Ripping	**	***	***
Weed control	**	***	***
Interactions			
Seedling quality/Handling	ns	ns	ns
Seedling quality/Ripping	**	**	**
Handling/Ripping	ns	ns	ns
Seedling quality/Weed control	**	*	ns
Handling/Weed control	ns	ns	ns
Ripping/Weed control	ns	ns	ns
Seedling quality/Handling/Ripping	ns	ns	ns
Seedling quality/Handling/Weed control	ns	ns	ns
Seedling quality/Ripping/Weed control	**	**	***
Handling/Ripping/Weed control	ns	ns	ns
Seedling quality/Handling/Ripping/Weed control	**	ns	ns

ns not significant,
* $p \leq 0.05$,
** $p \leq 0.01$,
*** $p \leq 0.001$

probably because the planting site in this trial is a harsh environment compared with the benign sites in the studies mentioned above; in fact, it is more in keeping with many New Zealand forest sites. However, the outcome from the trial discussed in this paper reinforces that earlier work, but with a much greater impact on survival.

Survival should exceed 80% for *P. radiata* establishment. Even using "best practice" seedlings with ripping and post-plant weed control, survival dropped from 93% for "best practice" handling to 73% for "conventional" handling. A 73% survival is not acceptable in plantation forestry in New Zealand. Survival exceeded 80% with treatment combinations which included "best practice" seedlings with "best practice" handling. Weed control was also important. The use of conventional seedlings and no weed control gave four out of five of the poorest tree survivals.

The effects of ripping were not as clear cut. In the absence of weed control, ripping improved survival, whereas in the presence of weed control, survival was greater in the non-ripped plots in three out of four possible comparisons. These results are somewhat contrary to what was expected. Cullen & Mason (1981) noted that ripping generally improves survival and often improves initial growth in most New Zealand conditions. Possibly, in the plots not sprayed with herbicide, ripping gave some degree of weed control in the centre of the ripped zone. However, for "best practice" seedlings with "best practice" handling, the treatment combination of weed control and ripping gave the best overall survival. This interaction between seedling quality, ripping, and weed control is difficult to interpret. Nevertheless, in determining survival, weed control is apparently a more critical factor overall than ripping.

Height and ground-line diameter

Details of mean height and ground-line diameter at age 3 years from planting are given in Table 1. The trends for height and diameter were similar. Seedling quality, ripping, and weed control all had significant effects on height and diameter (Table 2). Handling treatments had no significant effect, which is contrary to other work (Balneaves 1991; Balneaves & Menzies 1990; Balneaves *et al.* 1992). This was possibly because seedlings which were not going to perform well because of poor handling eventually died. Had these trees lived, their growth may have been checked, thus giving a growth difference due to handling treatments such as found in previous trials.

The best treatment combination for height and dbh was "best practice" seedling quality combined with ripping and weed control, while the worst treatment combination was "conventional" seedlings combined with no weed control and no ripping. Ripping appeared to be a more beneficial treatment for seedlings of "best practice" quality, while weed control appeared to be more important for "conventional" seedlings.

In a comparable trial with *P. taeda* in Oklahoma, ripping combined with herbicide application (hexazinone) was the most effective treatment in conserving soil water and reducing competing biomass (Wittwer 1986). Height and ground-line diameter after two growing seasons were significantly increased by ripping and, particularly, by weed control, but the best growth responses were achieved with the combined ripping/herbicide treatment. Wittwer's early results were very similar to those published here. However, results of a *P. radiata* trial planted near Rotorua led Brunsden (1980) to conclude that weed control alone gives the best overall early growth response on certain types of sites. Ripping, which resulted in poorer growth, was not recommended for sandy loam pastureland soil.

Results for Age 13

The results of the analyses of variance are given in Table 3 and they are almost identical for height, dbh, and volume, in terms of significance. The most significant factor was weed

TABLE 3–Levels of significance for the analysis of variance at age 13 years

Treatment	Height	dbh	Volume
Seedling quality	**	**	**
Handling system	ns	ns	ns
Ripping	**	*	*
Weed control	***	***	***
Interactions			
Seedling quality/Handling	ns	ns	ns
Seedling quality/Ripping	ns	ns	ns
Handling/Ripping	ns	ns	ns
Seedling quality/Weed control	ns	ns	ns
Handling/Weed control	ns	ns	ns
Ripping/Weed control	ns	ns	ns
Seedling quality/Handling/Ripping	ns	ns	ns
Seedling quality/Handling/Weed control	*	**	**
Seedling quality/Ripping/Weed control	ns	ns	ns
Handling/Ripping/Weed control	ns	ns	ns
Seedling quality/Handling/Ripping/Weed control	ns	ns	ns

ns not significant,
* $p \leq 0.05$,
** $p \leq 0.01$,
*** $p \leq 0.001$

control, which explained between 48% and 52% of the total variation. This was followed by seedling quality which explained between 8% and 9% of the total variation, and ripping which explained between 4% and 6%. There was a significant interaction between seedling quality, handling, and weed control, which explained between 4% and 7% of the total variation. The effect of handling was not significant on its own, and all other interactions were not significant.

The effects of ripping are presented separately in Table 4, because of the significance of this treatment as a main effect but lack of significant interactions with other treatments. Ripping had a small positive effect on growth resulting in a 7% increase in volume.

The effects of seedling quality, handling practice, and weed control on growth are given in Table 5. Weed control consistently gave better growth, and was significantly better than no weed control except for dbh and volume of "best practice" seedlings with "conventional" handling. The best treatment combination, which resulted in significantly better height, dbh, and volume, was "best practice" seedlings with "best practice" handling and weed control. In all other combinations, seedling handling did not have a significant effect.

The effects of all the different treatment combinations on volume can be compared with the best treatment combination of weed control, "best practice" seedling quality, and "best

TABLE 4—Effect of ripping on mean tree height (m), mean dbh (cm), and mean volume (m^3) at age 13 years

	Height (m)	dbh (cm)	Volume (m^3)
Ripping	12.3a	27.4a	0.28a
No ripping	11.9b	26.5b	0.26b

Means followed by the same letter are not significantly different at the 5% level according to the least significant difference (LSD) test.

TABLE 5—Effects of seedling quality, handling practice, and weed control on subsequent mean tree heights (m), mean dbh (cm), and mean volume (m^3) at age 13

Weed control	Seedling quality			
	"Best practice" handling		"Conventional" handling	
	Best practice	Conventional	Best practice	Conventional
Tree height (m)				
+	13.2 a	12.6 b	12.4 bc	12.6 b
–	11.5 de	12.0 cd	11.2 e	11.4 e
Tree dbh (cm)				
+	30.3 a	28.2 b	27.7 b	27.9 b
–	25.1 cd	26.8 bc	25.2 cd	24.4 d
Tree volume (m^3)				
+	0.37 a	0.31 b	0.29 b	0.30 b
–	0.23 cd	0.26 bc	0.22 d	0.21 d

Means followed by the same letter are not significantly different at the 5% level according to the least significant difference (LSD) test.

practice" handling (Table 6). Eliminating one or more factors of quality establishment reduced mean tree volume from 16% to 43%, depending on which factors were removed. This serves to demonstrate that all factors in establishment are important, some more than others, for maximising productivity over the long-term.

TABLE 6–Effects of eliminating weed control, "best practice" seedling quality and "best practice" handling on volume growth at age 13

Treatment			Mean tree volume (m^3)	Loss (%)
Weed control	Seedling quality	Handling		
+	Best practice	Best practice	0.37	–
+	Best practice	Conventional	0.31	16
+	Conventional	Conventional	0.30	19
+	Conventional	Best practice	0.29	22
–	Best practice	Conventional	0.26	30
–	Best practice	Best practice	0.23	38
–	Conventional	Best practice	0.22	41
–	Conventional	Conventional	0.21	43

It is important to note that because the different treatment combinations resulted in considerable variation in survival, there was also considerable variation in the selection ratios at final thinning. For the best survival (93%) the selection ratio was approximately 3.3, compared with approximately 1.3 for the worst survival (36%). Treatment combinations with better survival, therefore, resulted in better selection at final thinning with the remaining trees more likely to have better growth rates. These differences in selection ratios could have influenced results for growth and subsequent yield at half-rotation.

CONCLUSIONS

The results of this trial are of particular interest because the long-term influence of different establishment practices, alone and in combination, is examined. Also, the planting site at Ashley Forest is harsher than the sites of other comparable establishment trials, and is more in keeping with many New Zealand forest sites. The results indicate that establishment treatments of seedling quality, seedling handling, cultivation by ripping, and weed control can have significant effects on survival and tree growth even at half-rotation 13 years after planting. These results are still very relevant today because little change has been made to seedling quality, seedling handling, and establishment practices in the last 15 years.

Weed control was the most significant treatment, followed by seedling quality, handling, and cultivation by ripping. The best treatment combination was "best practice" seedling quality, "best practice" handling, ripping, and weed control. Seedling handling practices had a significant effect on survival, but not on growth responses, which was contrary to results from other comparable trials. This result may have been due to the harsher environment of this trial compared with the more benign sites of the other trials, i.e., seedlings which were not going to perform well because of poor handling practices died before age 3 years. Had these trees lived, their growth may have been checked, thus giving growth differences due to handling treatments such as found in the other trials.

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