Effects of cultivation method on the early growth of *Pinus radiata* on a low-quality site in north-eastern Tasmania

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Abstract

Survival and growth of Pinus radiata *on a low-quality texture-contrast soil in north-eastern Tasmania were compared over a five-year period following five different cultivation treatments: no cultivation, ripping, mounding, ripping + mounding or spot cultivation. Soil penetration resistance after two years, and root abundance after 4.5 years, were also measured.*

After five years, there were no significant differences in survival between treatments. Ripping + mounding produced the best height growth after five years, followed by mounding, ripping, spot cultivation and lastly no cultivation. However, only mounding and ripping + mounding produced significantly greater height growth compared to no cultivation. Comparisons of plot mean basal area (m^2) and volume per hectare (m^3 ha^{-1}) showed trends similar to mean height after five years, with ripping + mounding producing the highest basal area and volume. However, only the differences between ripping + mounding and no cultivation were significant. Soil penetration resistance, measured after two years, was significantly lower at depths <45 cm following either ripping + mounding or spot cultivation compared to no cultivation. Root abundance after 4.5 years was significantly higher following ripping + mounding compared to the other four treatments.

Growth was therefore consistently superior following ripping + mounding when compared to the other treatments, although the results indicate that any type of cultivation is preferable to no cultivation at all. On highly erodible soils, such as those at the trial site, spot cultivation might be preferable to continuous cultivation (ripping and/or mounding) in order to minimise the risk of erosion and subsequent pollution of waterways by suspended sediments.

Introduction

Mechanical site cultivation prior to planting is generally regarded as being essential for the survival and growth of forest plantations. However, results of trials in north-western Tasmania and south-eastern Victoria (Holz *et al.* 1999) have shown that cultivation does not always improve the early growth of plantations. This lack of response in some soils is presumed to be due to inherent soil physical conditions, notably free drainage and good structure, that favour penetration of the soil by tree roots without the need for mechanical amelioration of soil structure or porosity. Furthermore, Holz *et al.* (1999) showed that deep ripping was effective only in soils with poorly structured subsoils or compacted layers. However, the authors noted that cultivation such as mounding did improve the survival rate of trees planted in freely drained and well-structured soils that did not respond to ripping. Smethurst (2004) later summarised results of numerous cultivation trials in south-east Australia and concluded that a combination of ripping and mound-ploughing was likely to result in the best tree growth at most sites.

Large areas of hilly land currently (or previously) carrying dry eucalypt forest occur in north-eastern Tasmania. These are low-quality sites with nutrient-poor soils, and often have restricted rooting depth due to sub-surface hardpans and/or coarsely structured subsoils (Laffan *et al.* 1996). Mechanical site cultivation using either spot or continuous ripping + mounding is almost always carried out by forest managers on such sites prior to planting. A recent comparison in Tasmania (Laffan *et al.* 2003a) of the effects of spot cultivation (Ro-tree cultivator head mounted on an excavator) versus continuous ripping + mounding (ripper-mounder unit mounted on a high-powered bulldozer) showed that after seven years there was a trend towards higher volume growth following spot cultivation. On low-quality sites with poorly structured soils the initial trend was for higher volume growth following ripping + mounding in the early years (up to age 4 years), after which the trend was for spot cultivation to result in higher volume growth. However, these differences were not statistically significant (Laffan *et al.* 2003a). This study also observed lower levels of erosion following spot cultivation compared to the continuous ripping + mounding treatment.

Results are presented here of a trial established on a low-quality site in north-eastern Tasmania to investigate the effects of different cultivation treatments on the survival and growth of *Pinus radiata*.

The study area

The trial was located approximately 7 km north-east of Scottsdale in north-eastern Tasmania, on mainly undulating slopes underlain by Devonian granite at altitudes between 160 and 190 m. Mean annual rainfall for the location was between 900 and 1000 mm, and the native vegetation was originally dry open eucalypt forest dominated by *Eucalyptus obliqua* and *E. amygdalina*.

The soils were mapped as Jensen Association (Grant *et al.* 1995). This map unit is dominated by the Jensen soil profile class, defined as an imperfectly to moderately-well drained texture-contrast soil with low permeability. Soil profiles are characterised by dark-coloured coarse sandy loam topsoils overlying bleached coarse sand sub-surface layers that in turn overlie yellowish-brown clay subsoils. The lower parts of the bleached layers are invariably massive and hard, forming an impediment to root penetration. Nutrient levels are low throughout, and erodibility is rated as high. Wurrawa soils with gradational texture-profiles (Laffan *et al.* 2003b) occur as a minor component within the Jensen soil association. They are characterised by very thin (<5 cm) dark-coloured sandy loam topsoils overlying yellowish-brown clay loams and clays. Nutrient levels are low and erodibility is rated as moderate.

Methods

The compartment was logged (clearfell) in 1998 and cultivation carried out between January and April 1999. Ripping, to a depth of approximately 70 cm, and/or mounding were carried out using a ripper-mounder unit attached to a large bulldozer. Spot cultivation was completed with a Wilco® head mounted to an excavator. The area was planted in July 1999 (c. 1111 stems ha^{-1}) with a basal application of fertiliser carried out soon after. No further weed control or fertiliser applications were carried out.

There were three replicates of the five different treatments, a total of 15 plots, with each plot having dimensions of about 60 m long by 15 m wide (five rows). The outer rows of each plot were left as buffers and measurements were confined to the three central rows, each row containing about 20 trees. Plot size thus varied from 0.044 ha to 0.059 ha, and the number of trees measured in each plot varied from 60 to 64.

For each tree, measurement of total height was made every August starting in 2000, and diameters (DBH) were also recorded in the third (2002), fourth (2003) and fifth (2004) years. Tree basal area was then calculated where:

$$\text{Tree basal area } (m^2) = \pi \times \left[\frac{DBH}{2}\right]^2$$

Tree volume (m^3) was then calculated using a cone function (because the trees were too small to use a *Pinus radiata* taper function) where:

$$\text{Tree volume } (m^3) = \frac{\pi}{3} \times \text{height} \times \left[\frac{DBH}{200}\right]^2$$

Data were then summarised to obtain the plot mean tree height (m), plot mean basal area (m^2) and total volume per hectare ($m^3\ ha^{-1}$).

Rather than analysing the data separately for each year, the statistical analysis used linear mixed models (lme in Splus software) fitting either a quadratic (for height) or linear (for volume and basal area) function to the plot means (Pinheiro and Bates 2000). The most general model for a plot-level observation included (a) a function for replicate effects, (b) a function for treatment effects and for the interaction between replicates and treatments, and (c) random regressions for plot effects (to allow for additional variation amongst plots). Finally, a power function accounted for variance heterogeneity.

Measurement of soil penetration resistance was carried out using an electronic-recording cone penetrometer (Rimik CP20) in September 2001 to determine whether significant differences in soil strength (and hence ease of root penetration) occurred between treatments. Because of difficulties in obtaining valid readings resulting from sub-surface obstructions such as roots and stones, measurements of penetration resistance were limited to just one replicate (plot) each of the no-cultivation, ripping + mounding and spot cultivation treatments. For each treatment, penetration resistance was sampled at 30 locations, and at depths of 2 cm, 6 cm and 10 cm and then intervals of either 5 cm or 10 cm to a maximum depth of 60 cm, either in the centre of the rows or on the mounds, and at a distance of approximately 50 cm from each tree. The initial reference (0 cm) was taken as the ground surface (no cultivation) or top of the mound (spot cultivation and ripping + mounding). At the time of measurement all soils were considered moist. Penetration resistance data were analysed by ANOVA based on 30 replicates per treatment.

At age 4.5 years, root abundance was assessed. Four trees from each treatment (2 trees from each of replicates 1 and 3) were selected randomly. At the base of each tree, a trench was dug to a depth of 1 m and a cross-section of the root-ball was viewed. The number of roots (> 1 mm diameter) over an area of 2 m^2 was then counted using a steel grid 1 m high by 2 m. Root abundance data were analysed by ANOVA based on 4 replicates per treatment.

Results and discussion

Results of survival over the five years (2000 to 2004) are shown in Table 1. In the second year (2001), survival following ripping + mounding and mounding was significantly higher than that following no cultivation. However, there were no significant differences in survival between the treatments after five years.

Table 1. Mean survival (%)

Treatment	Year				
	2000	2001	2002	2003	2004
Ripping + mounding	97[a]	96[a]	96[a]	96[a]	96[a]
Mounding	96[a]	95[a]	95[a]	93[a]	93[a]
Ripping	94[a]	93[ab]	90[a]	89[a]	89[a]
Spot cultivation	97[a]	94[ab]	94[a]	94[a]	94[a]
No cultivation	93[a]	87[b]	87[a]	87[a]	87[a]

Values within a column with the same letter are not significantly different at 95% confidence

The results for plot mean tree height (m) after five years (Table 2) show that height growth was greatest following ripping + mounding then, in decreasing order, following mounding, ripping, spot cultivation and no cultivation. As determined using a linear mixed model over all measurement years, there were no significant differences in height growth between the five treatments after the first year, but after the second year height growth following ripping + mounding was significantly greater than that following no cultivation. After three, four and five years of growth, height growth under both ripping + mounding and mounding was significantly greater than that following no cultivation.

Table 2. Mean tree height (m)

Treatment	Year				
	2000	2001	2002	2003	2004
Ripping + mounding	0.60[a]	1.30[a]	2.23[a]	3.44[a]	4.74[a]
Mounding	0.56[a]	1.18[ab]	1.93[a]	3.08[a]	4.26[a]
Ripping	0.49[a]	1.09[ab]	1.85[ab]	2.93[ab]	3.95[ab]
Spot cultivation	0.47[a]	0.99[ab]	1.70[ab]	2.77[ab]	3.81[ab]
No cultivation	0.45[a]	0.83[b]	1.32[b]	1.94[b]	2.64[b]

Values within a column with the same letter are not significantly different at 95% confidence.

Table 3. Mean tree basal area (m^2)

Treatment	Year		
	2002	2003	2004
Ripping + mounding	0.046[a]	0.13[a]	0.239[a]
Mounding	0.033[ab]	0.10[ab]	0.199[ab]
Ripping	0.025[ab]	0.075[ab]	0.139[ab]
Spot cultivation	0.021[b]	0.076[ab]	0.150[ab]
No cultivation	0.0076[b]	0.029[b]	0.064[b]

Values within a column with the same letter are not significantly different at 95% confidence

Table 4. Mean tree volume per hectare (m^3 ha^{-1})

Treatment	Year		
	2002	2003	2004
Ripping + mounding	0.96[a]	3.93[a]	9.90[a]
Mounding	0.69[a]	3.23[ab]	8.27[ab]
Ripping	0.43[ab]	1.92[ab]	4.68[ab]
Spot cultivation	0.32[ab]	1.73[ab]	4.52[ab]
No cultivation	0.17[b]	0.72[b]	2.09[b]

Values with a column with the same letter are not significantly different at 95% confidence

The results for plot mean basal area (m^2) (Table 3) and volume per hectare (m^3 ha^{-1}) after three, four and five years growth (Table 4) show a similar trend to mean height, with ripping + mounding producing the highest values for each year. However, as determined using a linear mixed model over all measurement years, the only significant differences in basal area and volume after five years were observed between ripping + mounding and no cultivation. In terms of the interaction between ripping and mounding, the effect of mounding was significant ($P < 0.01$) whereas the effect of ripping and its interaction with mounding were not significant.

Mean soil penetration resistance (kPa) for the three treatments is shown in Table 5. Penetration resistance was significantly lower throughout the 60 cm profile

Table 5. Mean soil penetration resistance (kPa) in 2001

Soil depth (cm)	Ripping + mounding	Spot cultivation	No cultivation
2	395[a]	485[a]	1227[b]
6	418[a]	544[a]	1724[b]
10	511[a]	789[a]	1832[b]
20	617[a]	812[a]	2142[b]
30	871[a]	994[a]	2074[b]
40	1170[a]	1170[a]	2485[b]
45	1011[a]	1381[b]	2679[c]
50	1193[a]	1791[b]	2723[c]
55	1264[a]	2139[b]	2642[b]
60	1181[a]	2446[b]	2566[b]

Values within rows with the same letter are not significantly different at 95% confidence

following ripping + mounding compared to no cultivation. Following spot cultivation, penetration resistance was significantly lower compared to no cultivation at depths <55 cm, but at greater depths no significant difference in penetration resistance was observed between the two treatments. Penetration resistance following ripping + mounding was only significantly different to that following spot cultivation at depths >40 cm, with ripping + mounding resulting in significantly lower penetration resistance than spot cultivation.

Ripping + mounding and spot cultivation were thus both effective in lowering penetration resistance, but spot cultivation was less effective in improving penetration resistance in the lower soil layers than ripping + mounding. Penetration resistance measured for all three treatments was less than 3000 kPa, a value considered to limit root penetration by *P. radiata* (Sands *et al.* 1979). However, other studies have indicated that penetration resistance >2500 kPa will restrict tree root growth (Moffat and Boswell 1997), and this value was exceeded in subsoils 45 cm or deeper in the no cultivation treatment. Higher values of penetration resistance would be expected to occur more commonly when the soils dry out over summer.

Mean root abundance per unit area measured of the soil profile after 4.5 years growth followed a similar trend to the results of tree growth. The highest abundance of roots occurred following ripping + mounding (42.3) followed by mounding alone (22.8), ripping (19.5), spot cultivation (16.5) and no cultivation (16.5). The abundance of roots following ripping + mounding was significantly greater ($P < 0.01$) than the remaining four treatments, but no other differences were significant.

Conclusions

Measurement of *Pinus radiata* on a low-quality site following five cultivation treatments showed that, after five years, ripping + mounding produced the best survival and growth.

Mean volume per hectare following ripping + mounding was over four times greater than that following no cultivation, and was over twice that following either ripping or spot cultivation. Although standing volumes after ripping or spot cultivation were twice that observed under no cultivation, the differences were not significant. Similarly, although mounding resulted in a standing volume almost four times greater than that following no cultivation, the difference was not significant. This is a likely effect of the low level of replication ($n = 3$ plots) throughout this study, and consequently the limited power of the statistical analysis. Because the trends in growth for each treatment are diverging with age, it is unlikely that growth following either ripping, mounding or spot cultivation will catch up with, or exceed, growth under ripping + mounding during the current rotation.

These results demonstrate that ripping + mounding produced the best survival and growth of *Pinus radiata* on these soils, but they also suggest that any cultivation prior to planting is preferable to no cultivation. On highly erodible soils, such as those at the trial site, spot cultivation might be considered preferable to continuous cultivation (ripping and/or mounding) in order to minimise the risk of erosion and subsequent pollution of waterways by suspended sediments.

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