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***Pinus radiata* response to ripping, weed control and fertilization at four ex-pasture sites**
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Public

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Sustainable Management Program

Project B1: Site productivity

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PRIVATE FORESTS TASMANIA

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Summary

Private Forests Tasmania and the CRC for Sustainable Production Forestry have been collaborating since 1999 to test the need for ripping, weed control and fertilization on dry, ex-pasture sites in Tasmania. Two sites were near Ouse, one near Epping Forest and one near Pipers River. The need for ripping in the presence of mound-ploughing was examined at all sites, but only at Epping Forest was the need for ripping examined in the absence of mounding. Only at the Ouse sites was fertilization examined, including DAP and KCl placement and rates. Weed control was examined at the Ouse and Pipers sites.

Despite drought stress, browsing damage and a lack of replicated cultivation treatments, the following conclusions were drawn. Ripping, in the absence of mounding, positively effected tree survival and growth at Epping Forest. Ripping with mound-ploughing appeared to benefit tree survival and growth at Epping Forest, Ouse Clay and Ouse Sand, but the effect was insignificant. At Pipers, ripping with mound-ploughing did not affect tree survival or growth. Fertilizers were not required for adequate survival and growth during the first year, but fertilizing Ouse Sand with surface-applied KCl placed closer than 20 cm from the seedling increased mortality. Weed control was beneficial at Pipers, but not at Ouse Clay or Ouse Sand.

The following recommendations were made. Deep rip (70 cm depth) dry, ex-pasture sites whether mound-ploughing or not. However, if deep ripping is not possible, mound-ploughing alone should be adequate. Dry, ex-pasture sites are likely to have adequate N, P and K fertility for the first year or two after planting. Later applications of N and K may be necessary. Base the assessment of soil fertility on fertilizer history of a site, local experience, and the use soil and foliar analyses in conjunction with reliable critical concentrations as they become available. The following research is recommended to provide a basis for further refinement of these recommendations: determine the relationship between the extent of ripping (vertically and horizontally) and tree growth on dry, ex-pasture sites, and the salient mechanisms involved; refine the critical soil and foliar nutrient concentrations for *P. radiata* established on dry, ex-pasture sites.

Introduction

Many farm-foresters are planting *Pinus radiata* or other forest plantation species in dry regions of Tasmania under the guidance of staff from Private Forests Tasmania. Establishment prescriptions for cultivation, weed control and fertilization for these sites have been drawn generally from experience in wetter, cooler regions where the soils and type of weed competition are also different. Sites of past experience were also generally 'ex-forest' of low fertility. Hence, there has been a need to refine establishment guidelines for plantations on drier, ex-pasture sites.

Management during the first year or two after planting is a critical determinant of the profitability of forest plantations, because the harvestable yield and quality of wood is directly affected by survival and growth rates during this phase of the crop. Some key management options are cultivation, weed control and fertilization.

Some form of cultivation is commonly used prior to planting because there is ample evidence that it enhances survival and subsequent growth rates under a variety of conditions (Attiwill and Adams 1996, Fisher and Binkley 2000). There are many mechanisms by which cultivation affects tree growth, but rarely have salient mechanisms been identified in specific cases. For example, cultivation usually affects aeration (drainage) and water availability, soil strength, weed growth, nutrient availability, and soil temperature, but relationships between these factors, soil properties, other site conditions, and the specific cultivation action are poorly defined. Hence, it is very difficult to predict the impact of cultivation on tree growth at specific sites.

Experience indicates that some degree of mound ploughing is almost universally beneficial for the establishment of pine plantations on ex-forest sites in south-eastern Australia, except on deep, well-structured soils with clay-loam surface textures, but there is little need to deep rip, e.g. to 70 cm depth (Holz et al. 1999, Lacey *et al.* 2001, Turvey and Cameron 1986). In south-eastern Queensland, small mounds and shallow ripping depths are adequate (Costantini *et al.*, 1995). There has been less experience on ex-pasture sites, but, in Victoria, ripping was of little benefit when large mounds were used (Bird *et al.* 2000, Measki *et al.* 1998). Despite doubts about the need for deep ripping, it is still widely used, because it is thought to either increase access by tree roots to water or nutrients in subsoils, or to improve physical conditions in the surface that accompany improved shattering of cloddy, root mats of pasture when one or more rippers are used. None of this cultivation experience has been on sites similar to those used for *Pinus radiata* plantations in the dry regions of Tasmania. Hence, the benefits of ripping and mound-ploughing needed to be defined under these conditions.

Weed control is also considered essential for successful plantation establishment in most circumstances (Adams and Attiwill 1996, Frelmin and Misic 1999, Nambiar and Sands 1993, Mendham et al. 1999), but previous experience may not be directly applicable to dry, ex-pasture sites where weeds may be slow to re-establish after cultivation.

The availability of nitrogen (N) and phosphorus (P) at ex-pasture sites ranges from quite high to very low, but, on average, N and P availability is higher than at ex-forest sites (Osborne et al. 2001). Graziers rarely apply potassium (K), causing ex-pasture sites to be severely K deficient in some circumstances (Smethurst et al. 2001). Apart from choosing which nutrients to apply, one also needs to consider the rate of fertilization and its placement, but prior to the research reported below there had been no systematic attempts to refine prescriptions for dry, ex-pasture sites in Tasmania. It is a concern that fertilizer may be used when not needed, and that, when used, careful placement will be needed to maximize the benefits. For example, it is common practice to place fertilizer in a spot close to the base of the seedling, but CRC research has shown that when placed too close (either on the surface or buried) survival rates of young trees are significantly reduced (Smethurst and Appleton 1999). In the same study it was found that omitting K would retard the growth of seedlings on some soils.

Objectives of the research reported here were to determine the effects of various establishment options (cultivation, weed control and fertilization) on the growth of *Pinus radiata* plantations on dry, ex-pasture sites in Tasmania.

Methods

Sites

Four pasture sites were used for the study, two of which were located on one farm near Ouse (Fig. 1); general locations are indicated in Fig. 2. Soil profile descriptions for 3 sites are provided in Tables 2-4, and soil chemistry of the Ouse sites in Table 5. The soil at Pipers was a shallow duplex soil with a poorly drained, mottled clay B horizon.

Fig. 1. Staff from CSIRO and PFT researching *P. radiata* establishment practices on the ex-pasture, Ouse Clay site. Pictured are Keith Churchill (left), Philip Smethurst and Graeme Clarke (right); the photo was taken soon after planting.

Table 1. Some characteristics of the sites used for the study.

	Epping Forest	Ouse Clay	Ouse Sand	Pipers River
Rainfall (mm $year^{-1}$)	684 (Launceston Airport)	546 (Millbrook)		750 (Lebrina)
Management History	Dry sclerophyll forest followed by improved pasture	Dry sclerophyll forest followed by improved pasture with small remnant patches of native trees: *Eucalyptus viminalis*, *Acacia melanoxylon*, *Acacia dealbata*, *Banksia marginata*, and *Bursaria spinosa*		Dry sclerophyll forest followed by improved pasture
Year Planted	1999	1999		1999
Soil Parent Material	Launceston basin sediments	Basalt	Sandstone	Sandstone

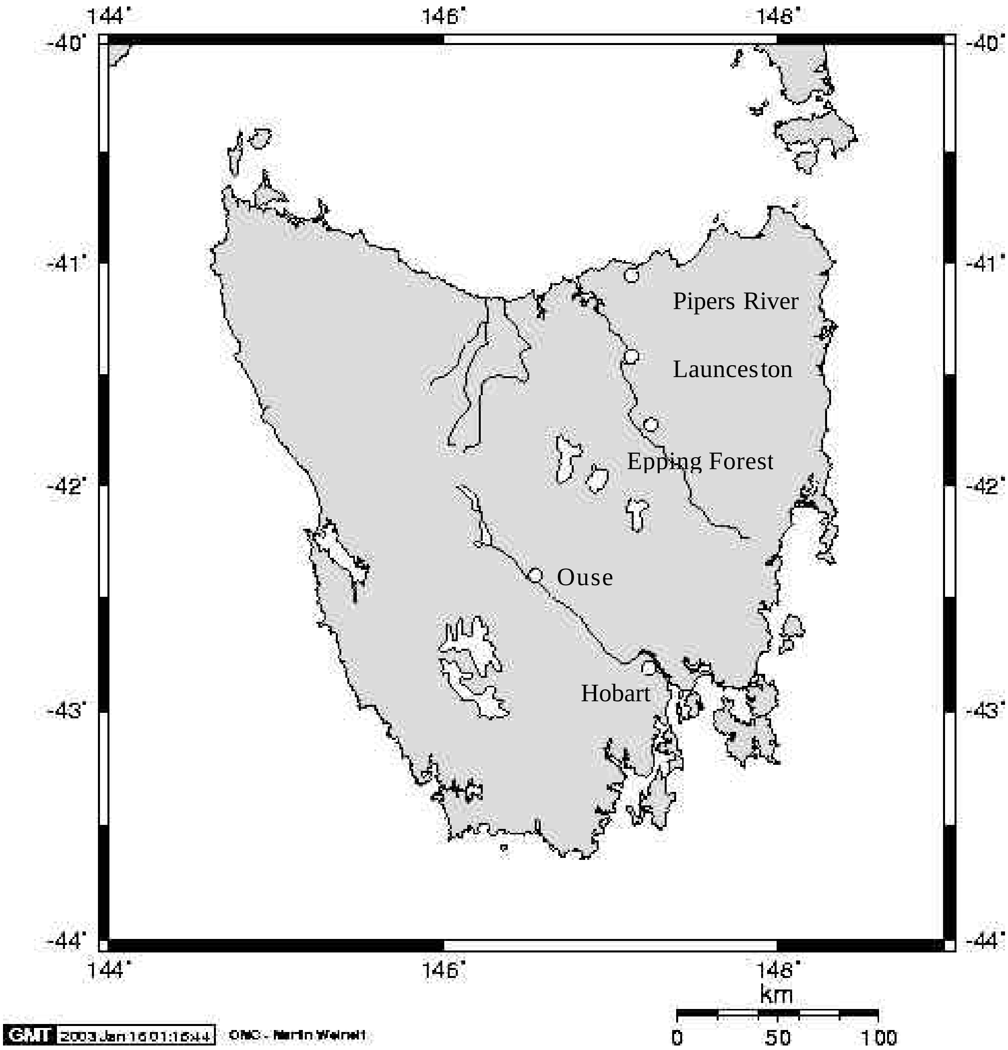


Figure 2. The three farms used for the study were located near Epping Forest, Ouse, and Pipers River, Tasmania; longitude (x gridline) and latitude (y gridline) is also indicated.

Table 2. Generalised soil profile description of the Epping Forest site (Brickenden Association).

Horizon	Depth (cm)	Texture and Rocks	Colour	Comments
A1	0-15	Dark gray sandy loam; 10-20% water worn quartz pebbles	10YR 4/1	Clear boundary to
A2	15-60	Grayish brown sandy loam; 20-50% water worn quartz pebbles	10YR 5/2	Clear boundary to
B	60-	Yellowish brown medium clay; ; 10-20% water worn quartz pebbles	10YR 5/4	

Table 3. Soil profile description of the Ouse Clay site.

Horizon	**Depth (cm)**	**Texture and Rocks**	**Colour**	**Comments**
A1	0-12	silty loam with 40-50% rock content (3-4 mm diameter)	dark reddish brown (2.5 YR 3/4)	none
A2	12-32	as above but with occassional 40-50 mm rocks	dark reddish brown (5 YR 3/4)	none
B	32-53	as above but containing larger 100 mm rocks	dark reddish brown (5 YR 3/4)	large floating rock

Table 4. Soil profile description of the Ouse Sand site.

Horizon	**Depth (cm)**	**Texture and Rocks**	**Colour**	**Comments**
A1	0-12	loamy sand, no rocks	dark gray (7.5YR 4/1)	clear boundary to next horizon
A2	12-27	loamy sand, no rocks	gray (7.5YR 6/1)	less organic matter than above horizon
B	27-47	sandy clay, no rocks	strong brown (7.5YR 5/8)	very compact and hard to break down and wet for texture analysis

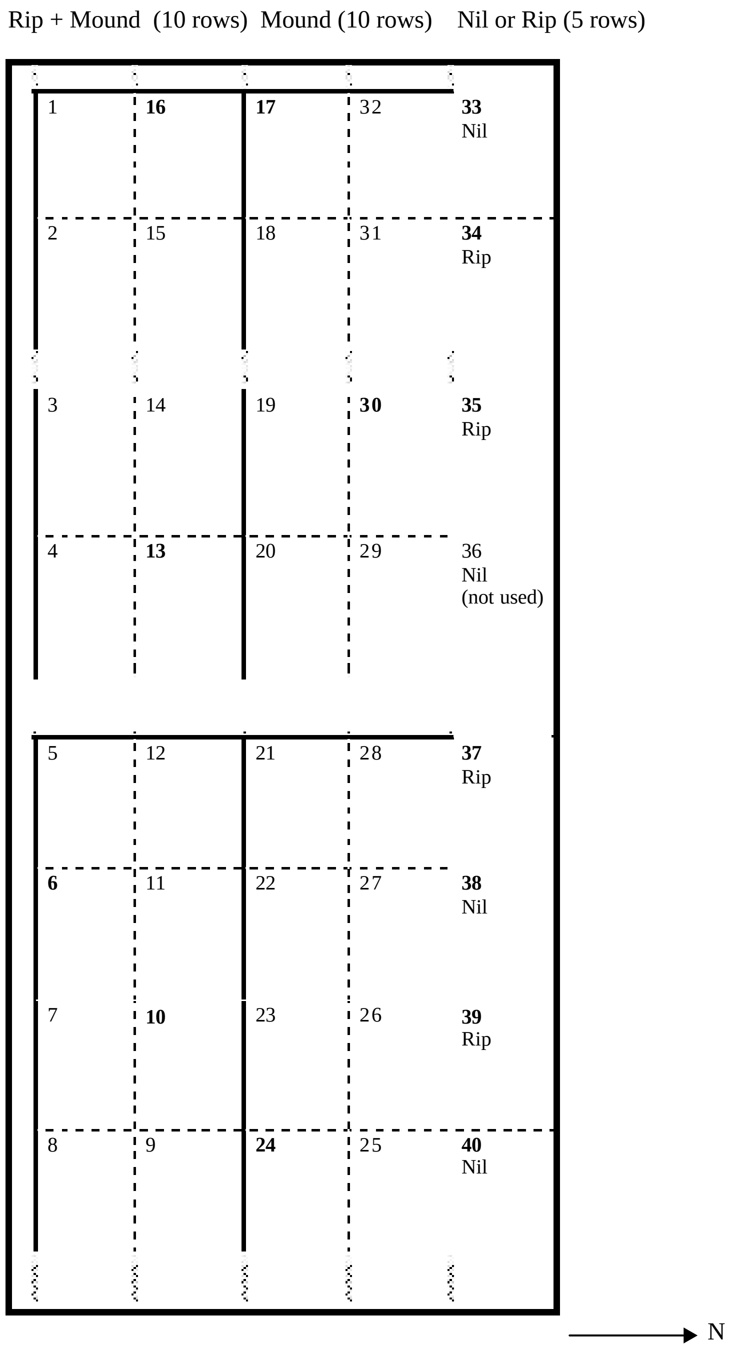
Experimental Designs and Treatments

Epping Forest

The objective of this experiment was to compare the effects of ripping and mounding on tree survival and growth. These two treatments were examined in a factorial design, i.e. all combinations of with and without each treatment, with 4 replicates, but the mounding and ripping+mounding treatments were not randomized (a layout of the site is presented in Fig. 3). Ripping was to c. 70 cm depth. Rows were c. 3 m apart, parallel to a native forest and a gradient in slope and soil A horizon depth (c. 80 cm in replicate 1 to c. 40 cm in replicate 4). Trees were c. 3 m apart within rows (1111 trees ha^{-1}). Plots consisted of 5 rows by 10 trees, all of which were measured.

Table 5. Soil chemistry at the study sites.

Site	Depth (cm)	Colwell P (mg/kg)	pH	EC (dS/m)	$CaCl_2$-P (mM)	Exchangeable Base Cations (mEq/100 g)				Total Concentrations (%)		
						Na	Ca	K	Mg	C	N	P
Ouse Clay	0-12	3.96	5.31	0.06	0.282	0.142	3.29	0.632	1.30	2.6	0.172	0.044
	12-32	1.43	5.96	0.076	0.068	0.149	1.99	0.158	2.17	0.9	0.058	0.036
	32-53	0.88	5.79	0.07	0.048	0.202	0.68	0.074	2.78	0.8	0.049	0.035
Ouse Sand	0-12	2.55	7.2	0.019	6.518	0.030	1.56	0.063	0.42	0.9	0.0482	0.005
	12-27	0.79	4.99	0.006	4.244	0.033	0.19.	0.020	0.02	0.3	0.0091	0.004
	27-47	0.32	5.09	0.041	0.092	0.361	0.08	0.134	3.98	0.4	0.0222	0.005



Nil = no cultivation treatment (control)
Measured plot numbers are shown in **bold.**

Fig. 3. Layout of the Epping Forest Experiment.

Ouse Clay and Ouse Sand

Three experiments were established at each of these sites, i.e. Experiments 1, 2 and 3 described below. After cultivation (4 m between rows) and pre-planting weed control, the sites were planted with *Pinus radiata* in July 1999; trees were 2 m apart within rows (1250 trees ha^{-1}).

Experiment 1: Ripping and Follow-Up Weed Control and Fertilization

The objective of this experiment was to compare the effects of ripping and follow-up weed control and fertilizer treatments on tree survival and growth. Ripping was not randomized, i.e. a ripped block and an unripped block were prepared at each site, and the weed control and fertilizer treatments were completely randomized four times within each block. After ripping, the sites were mound ploughed. Each plot consisted of 10 rows by five trees, the central 18 of which were measured.

Experiment 2: DAP Fertilization

The objective of this experiment was to compare tree survival and growth when three factors of DAP (diammonium phosphate) fertilizer were varied: distances from seedling, depth, and rate. The site was mound ploughed with routine pre- and post-planting weed control carried out during the first year, and further weed control during the second year. A randomized block design was used such that each replicate was chosen to be as uniform as possible for slope, weed status, and soil type, and treatments were randomized within each replicate. Treatments are described in Table 6. Fertilizer was applied on the down-hill side of the trees, and soil was lightly kicked over the surface applications. Each experimental plot consisted of 2 rows by 5 trees with no buffers between plots. The experiment included 3 replicates at the Ouse Clay site and 5 replicates at the Ouse Sand site.

Table 6. Treatments used in Experiment 2: DAP fertilization.

Treatment	Fertilizer Rate (g tree^{-1})	Mode of Application	Distance From Tree (cm)
1 (control)	0		
2	150	surface spot applied	0-5
3	150	surface spot applied	5-10
4	150	surface spot applied	10-15
5	150	surface spot applied	18-23
6	150	surface spot applied	28-33
7	150	slit applied	10-15
8	50	surface spot applied	0-5
9	50	surface spot applied	5-10

Experiment 3: K Fertilization

This experiment repeated Experiment 2, except K rather DAP fertilization was examined. Hence, the objective was to compare tree survival and growth when three factors of K fertilizer (muriate of potash) were varied: distances from seedling, depth, and rate. The site was mound ploughed with routine pre- and post-planting weed control carried out during the first year, and further weed control during the second year. A randomized block design was used such that each replicate was chosen to be as uniform as possible for slope, weed status, and soil type, and treatments were randomized within each replicate. Treatments are described in Table 7. As for Experiment 2, fertilizer was applied on the down-hill side of the trees (Fig. 4), and soil was lightly kicked over the surface applications. Each experimental plot consisted of two rows by five trees with no buffers between plots. The experiment included 3 replicates at the Ouse Clay site and 5 replicates at the Ouse Sand site.

Table 7. Treatments used in Experiment 3: K fertilization.

Treatment	Fertilizer Rate (g tree^{-1})	Mode of Application	Distance From Tree (cm)
1 (control)	0		
2	36	surface spot applied	5-10
3	36	surface spot applied	15-20
4	36	surface spot applied	25-30
5	36	surface spot applied	35-40
6	36	surface eyebrow (semi-circle) application	25-30
7	36	sub-surface applied in spade slit	25-30
8	18	surface spot applied	5-10
9	18	surface spot applied	15-20

Figure 4. The method used to accurately apply fertilizer at a given distance from the tree. This example is of K fertilizer applied to the Ouse Clay site.

Pipers

The objective of this experiment was to compare the effects of ripping and follow-up weed control on tree survival and growth. There were 2 replicates of ripping treatments (nil and to c. 70 cm depth), within each of which were 4 randomised replicates of two weed control treatments (nil and Velmac G yellow trigger applied c. one year after planting). Each plot consisted of 7 rows (3 m apart) by 7 trees (3 m apart), i.e. 1111 trees ha^{-1}, the central 25 trees of which were measured. A layout of the plots is shown in Fig. 5, including a fertilizer treatment that was not applied.

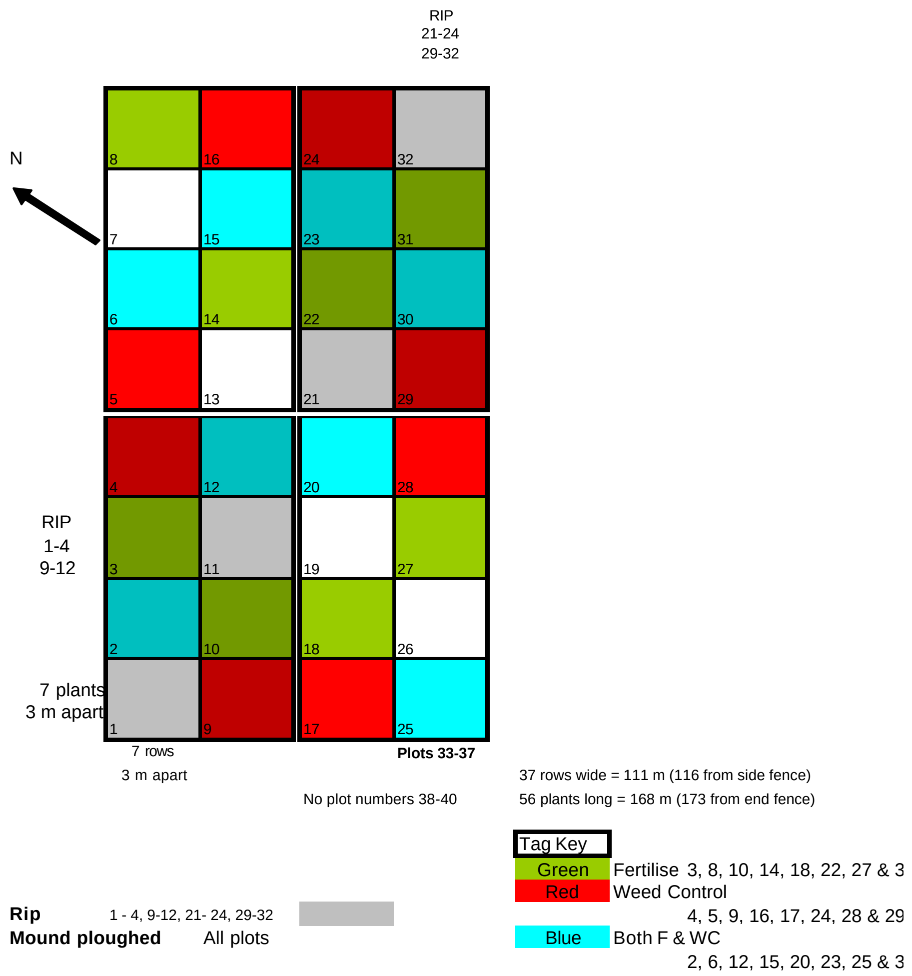


Fig. 5. Layout of the Pipers Experiment. Fertilizer treatments had not been applied by the time this report was prepared.

Measurements

Rainfall

Monthly and annual rainfall data were obtained from the Bureau of Meteorology for sites in the same districts as our experimental sites.

Tree Survival and Growth

At approximately 2 years of age, the numbers of live and dead trees per plot were recorded, as well as the heights and, at some sites, diameters (at 15 cm height, or 130 cm height if available) of the live trees. Seedling height at Ouse was also measured soon after planting. Survival, and average heights, diameters or the increment in an index of stem volume ($diameter^2$ x height = D^2H) were calculated per plot. Browsing damaged was scored at Ouse, and tree health and form, and weed cover, (1 worst, 5 best) were scored at Pipers; average values per plot were calculated.

Data were analyzed by standard statistical procedures (ANOVA, LSD, t-test) using Statgraphics® and Excel® software, but some compromises were necessary:

- *Epping Forest*: These data were analyzed using both a randomized, factorial design with 4 replicates and one missing plot, and using a 4-treatment ANOVA with 4 replicates. However, the non-random layout required that caution be used in attributing apparent treatment differences to the actual treatments.
- *Ouse Clay and Ouse Sands, Experiment 1*: Due to non-randomization of the ripping treatment, ripped and unripped areas were treated as separate experiments within which fertilizer and weed control effects were compared in a factorial analysis of variance with 3 or 5 replicates.
- *Pipers*: Not all plots were measured, but there were enough to examine ripping and weed control effects in a factorial design with 3 replicates.

Ripping effects were examined also in a two-way ANOVA using the four sites as blocks. Statements of significance refer to a 5% probability level that an incorrect conclusion is being drawn, i.e. P = 0.05, unless otherwise indicated.

Results

Rainfall

Rainfall patterns at Ouse indicated marked seasonality (Fig. 6), with peaks during September-November, and troughs during January-June, and annual totals were 462 mm for 1999, 526.6 mm for 2000, and 584.8 for 2001. The average annual rainfall for Ouse (Millbrook site since 1892) is 546 mm. Hence, trees at Ouse experienced a drought during their first year of growth.

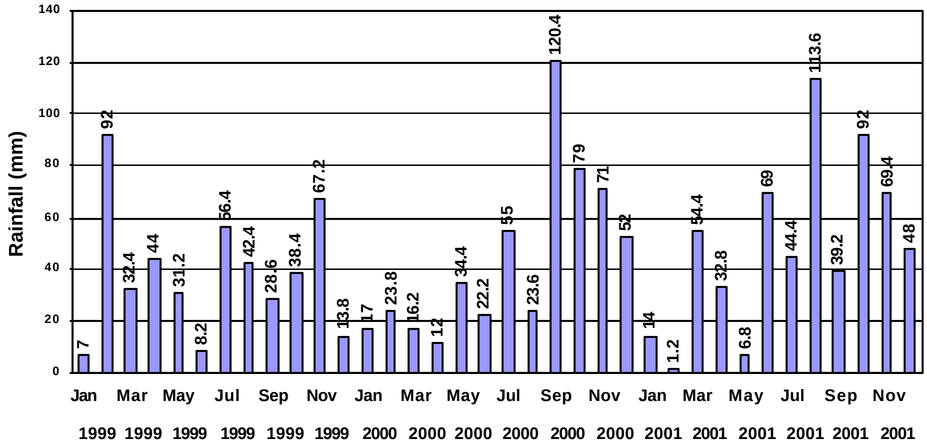


Figure 6. Monthly rainfall totals taken from Ouse (Millbrook) station, (42°28'54S, 146°42"40E)

Rainfall records were not available at the exact locality of the other sites, so the nearest station to each experiment was chosen to give an indication of precipitation in the area. Lebrina (est. 1980) was chosen as being closest to Pipers River and Launceston Airport (est. 1931) records were used for the Epping Forest site. Seasonality was also marked at these sites (Figs. 7 and 8). Annual total rainfall (mm) at Lebrina was 994.5mm for 2000, 1002 mm for 2001 at Lebrina. There were insufficient records for 1999 at Lebrina for an annual total. Annual total rainfall (mm) at Launceston Airport (mean annual 683.9 mm) was 641.2 mm for 1999, 658.4 for 2000, and 653.8 for 2001.

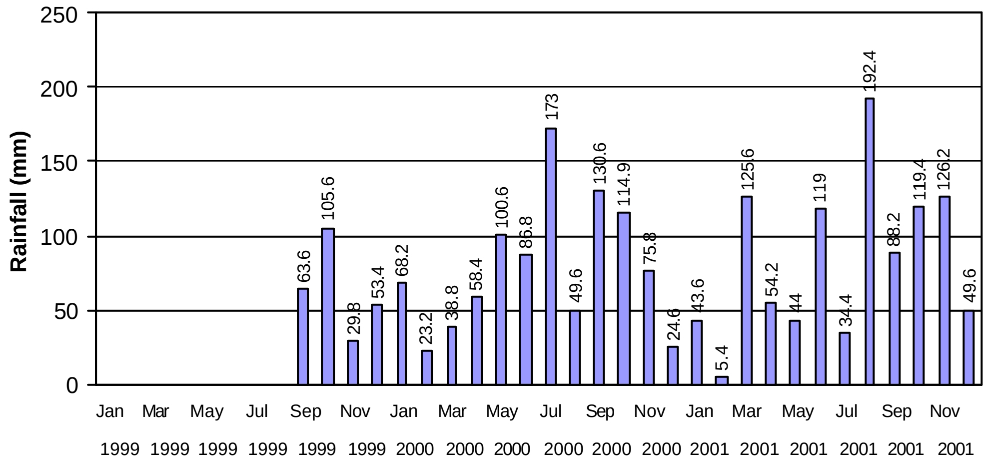


Figure 7. Monthly rainfall totals taken from Lebrina station, (41°11'12"S, 147°13"18E)

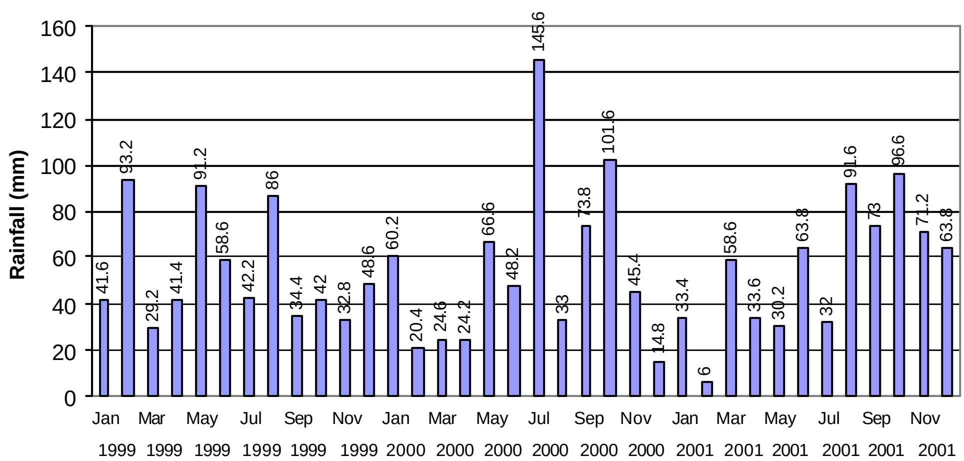


Figure 8. Monthly rainfall totals taken from Launceston Airport station, (41°32'26"S, 147°12"06E)

Tree Survival and Growth

Epping Forest

A factorial ANOVA indicated that the main effects of ripping and mounding on mortality were significant (P = 0.01 for ripping and P = 0.06 for mounding), and the interaction just insignificant (P = 0.09). However, the 4-treatment ANOVA indicated that the interaction was significant (P = 0.02), such that combined ripping and mounding was most effective but not significantly better than ripping or mound ploughing alone. The combination of ripping and mound ploughing reduced mortality. from 40.1% with no cultivation to 3% with both treatments (Fig. 7)

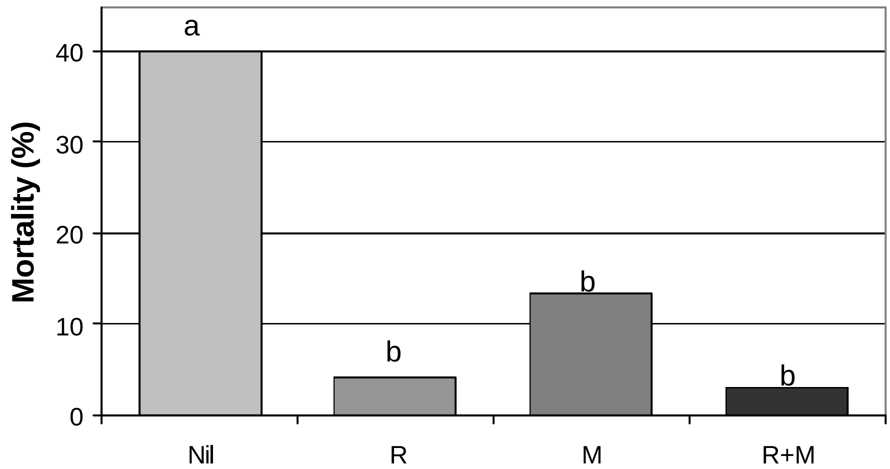


Fig. 9 . Effect of cultivation (R = ripping, M = mounding) on mortality of *P. radiata* at Epping Forest. Means accompanied by the same letter are not significantly different as indicated by a least significant difference. In the absence of mounding, it was very important to rip.

Mounding did not significantly affect tree height or diameter, but ripping significantly improved both these parameters (P = 0.02). On average, best growth was achieved in the ripped (but not mounded) treatment (Figs. 10 and 11).

Mortality and growth were unaffected by 'Replicate', i.e. slope position and depth of the A horizon.

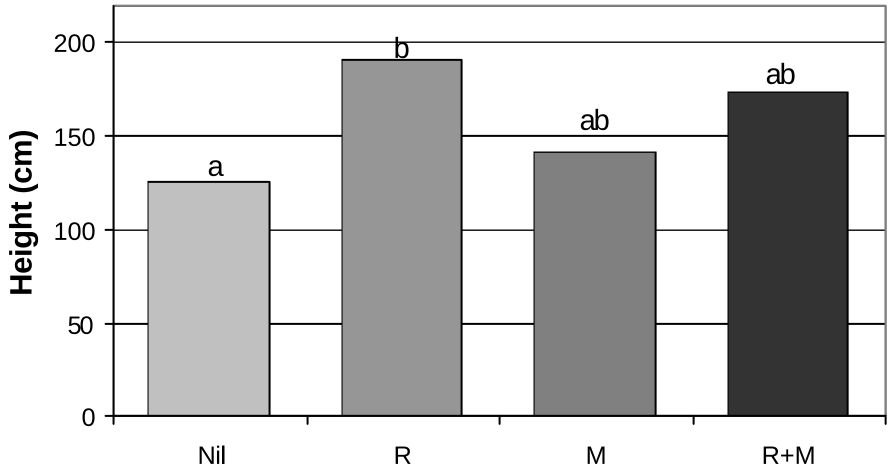


Fig. 8 . Effect of cultivation (R = ripping, M = mounding) on height growth of *P. radiata* at Epping Forest. Means accompanied by the same letter are not significantly different as indicated by a least significant difference. Ripping enhanced growth, but the effect of mounding was less clear.

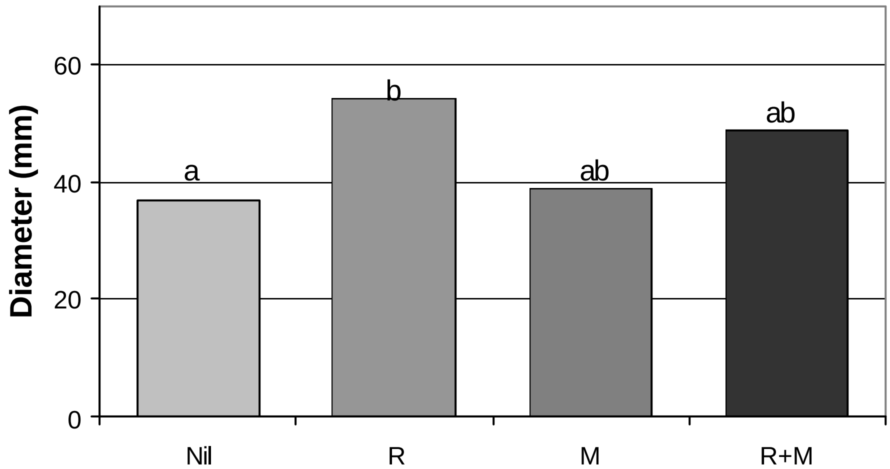


Fig. 11 . Effect of cultivation (R = ripping, M = mounding) on diameter growth of *P. radiata* at Epping Forest. Means accompanied by the same letter are not significantly different as indicated by a least significant difference. Ripping enhanced growth, but the effect of mounding was less clear.

Ouse Clay

Severe browsing was evident in all Ouse experiments, but its severity decreased with time. This trend may have been related to additional plantations being established adjacent to the experimental blocks offering alternative feed. Numerous scats found around the trees suggested that *Thylogale billardierii* (Tasmanian Pademelon), and *Macropus ruforiseus* (Bennett's Wallaby) may have been responsible for the browsing damage. There were no significant effects of treatment or replicate on browsing damage.

(a) Ouse Clay Experiment 1: Ripping and Follow-Up Weed Control and Fertilization

Follow-up weed control and fertilization did not significantly affect tree survival in either the ripped or unripped areas of the Ouse Clay site, but ripping increased survival from 81% to 98% ($P = 0.05$ by t-test) and height from 67 cm to 75 cm ($P = 0.04$).

(b) Ouse Clay Experiment 2: DAP Fertilization

DAP placement and rate did not significantly affect survival or growth at the Ouse Clay site , but all the fertilized treatments had on average a higher volume increment than the unfertilized treatment (Figs. 12 and 13).

(c) Ouse Clay Experiment 3: K Fertilization

Placing a high rate of KCl fertilizer (36 g) in a slit 25-30 cm from the seedling significantly reduced survival from 100% to 80% at the Ouse Clay site, but other forms of application had no significant effect on survival, including the same rate of fertilizer surface-applied much closer to the seedling (Fig. 14). Because growth was not significantly affected by these treatments (Fig. 15), the apparent effect of slit application on survival was probably not causal.

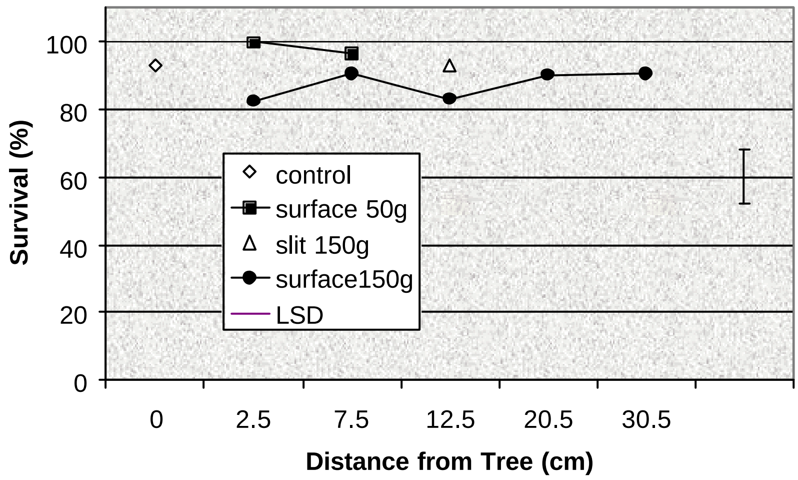


Fig. 12 . DAP placement and rate did not affect survival at the Ouse Clay site. No fertilizer was placed a 0 cm distance.

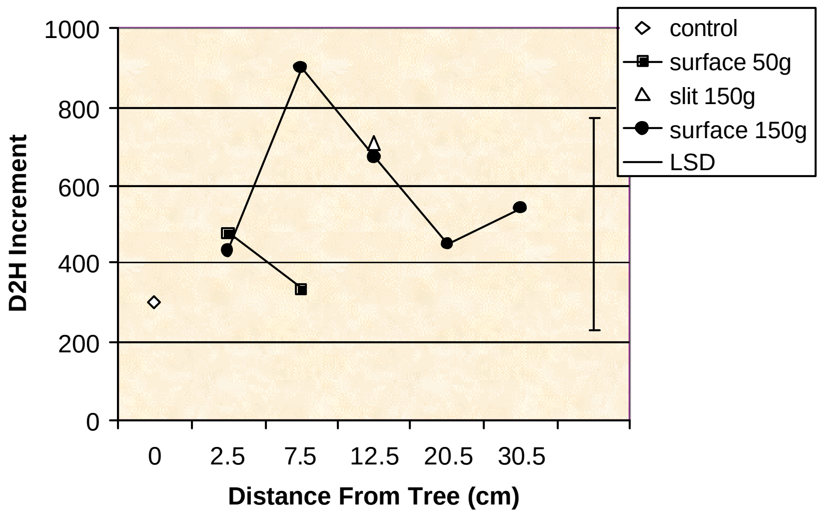


Fig. 13 . DAP placement and rate did not affect growth significantly at the Ouse Clay site as indicated by the increment in an index of stem volume (D^2H). No fertilizer was placed a 0 cm distance.

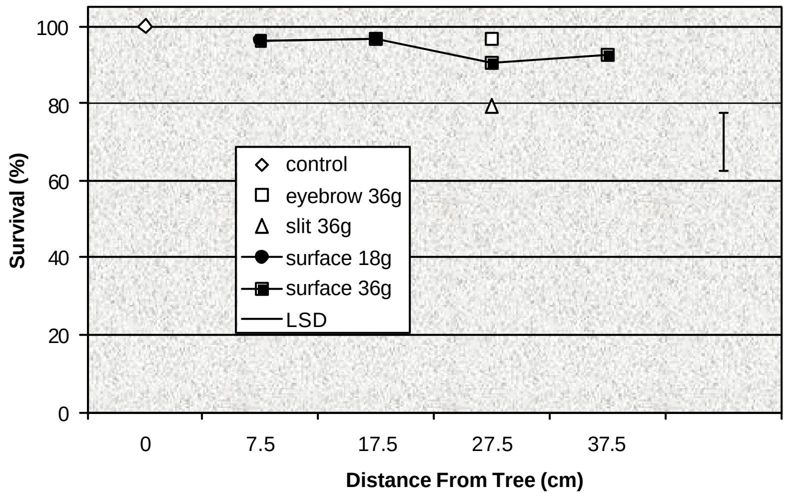


Fig. 14 . KCl placement and rate significantly affected survival at the Ouse Clay site only if the fertilizer was placed at a high rate (36 g) in a slit 25-30 cm from the seedling. No fertilizer was placed a 0 cm distance.

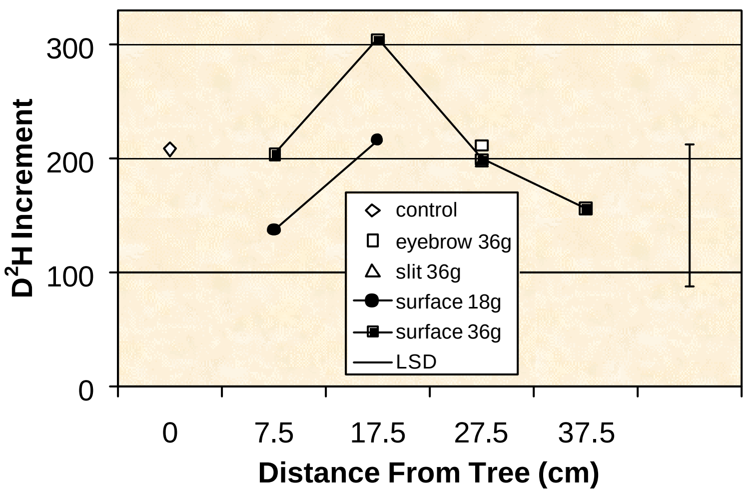


Fig. 15 . KCl placement and rate did not affect growth significantly at the Ouse Clay site as indicated by the increment in an index of stem volume (D^2H). No fertilizer was placed a 0 cm distance.

Ouse Sand

(a) Ouse Sand Experiment 1: Ripping and Follow-Up Weed Control and Fertilization

As for the Ouse Clay site, follow-up weed control and fertilization did not significantly affect tree survival in either the ripped or unripped areas of the Ouse Sand site. The effect of ripping on survival was also not significant (t-test), but height growth was increased by 66% from 68 cm to 112 cm (P = 0.0002 by t-test).

(b) Ouse Sand Experiment 2: DAP Fertilization

DAP placement and rate significantly reduced survival at the Ouse Sand site in some treatments, and there was a general trend for decreased survival in all fertilized treatments compared to the unfertilized control (Fig. 16). However, because there was not a consistent pattern with distance from the seedling or rate, these effects might not have been causal. This assertion is supported by the lack of effect of these treatments on growth (Fig. 17).

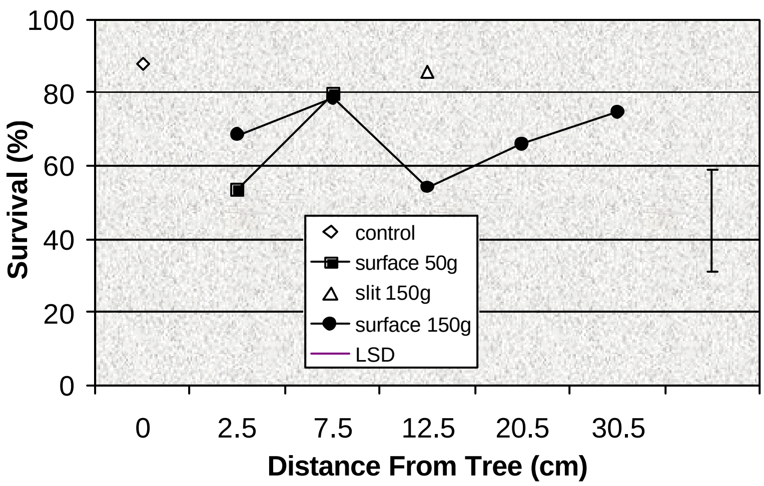


Fig. 16 . DAP placement and rate reduced survival at the Ouse Sand site in some treatments. No fertilizer was placed a 0 cm distance.

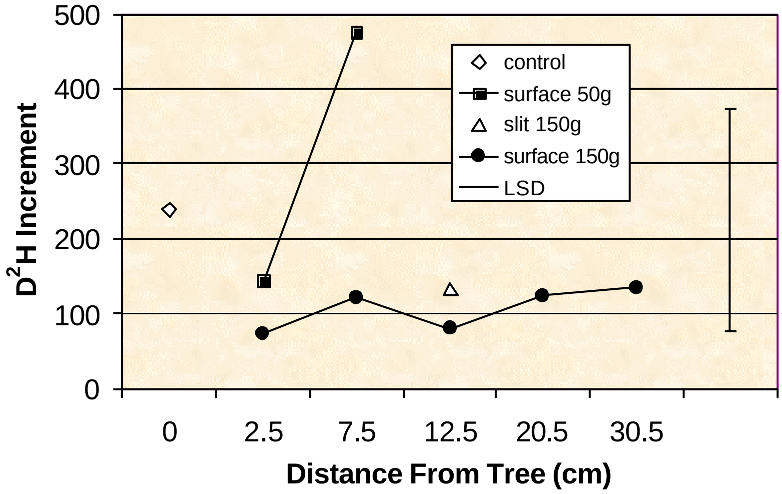


Fig. 17 . DAP placement and rate did not affect growth significantly at the Ouse Sand site as indicated by the increment in an index of stem volume (D^2H). No fertilizer was placed a 0 cm distance.

(c) Ouse Sand Experiment 3: K Fertilization

Placing a high rate of KCl fertilizer (36 g) on the surface 7.5 or 17.5 cm from the seedling reduced survival from 73% to less than 35% (with a sigmoidal trend between distance and survival), but use of half this rate or alternative placements had no significant effect (Fig. 18). Survivors of the 7.5. cm, surface, 36 g treatment grew significantly better than the unfertilized treatment, but this may not have been causal because it is not consistent with the lack of effect of other treatments on growth (Fig. 19)

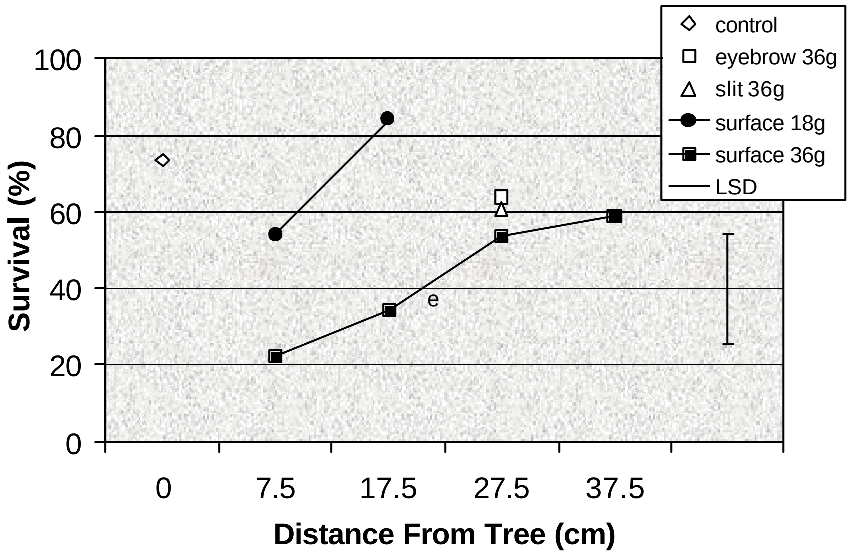


Fig. 18 . KCl placement and rate significantly affected survival at the Ouse Sand site only if the fertilizer was placed at a high rate (36 g) on the surface, 18 cm or closer from the seedling. No fertilizer was placed a 0 cm distance.

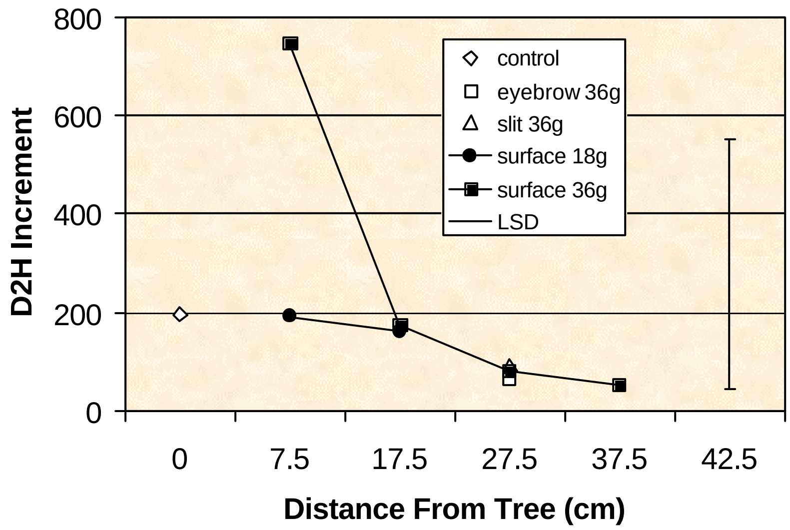


Fig. 19 . KCl placement and rate did not affect growth significantly at the Ouse Sand site as indicated by the increment in an index of stem volume (D^2H). No fertilizer was placed a 0 cm distance.

Pipers

There was no significant interaction between ripping and weed control for any parameter at the Pipers site, i.e. for health, form and weed scores, survival or tree growth, and there was also no significant main effect of ripping (control 2.7 m height, ripped 2.6. m, P = 0.3). Weed control, increased the weed score from 1.3 to 4.1 (P < 0.0000) and diameter at 15 cm height from 6.8 cm to 7.7 cm (P = 0.04), but not diameter at 130 cm height nor height itself.

Average Effect of Ripping

In a t-test paired by site, ripping increased average survival by 10%, but this was significant only at P = 0.23. Likewise, average height was increased from 137 to 155 cm, i.e. 14% increase, but this was significant only at the P = 0.22 level, and excluding the Pipers site from the analysis increased the P level to 0.11.

Discussion

Ripping

Although results suggested a positive response to ripping in tree survival or growth at the Ouse and Epping Forest sites, statistically this effect was significant at only the P = 0.22 level of probability, which indicates reasonable doubt that the observed differences were due to the treatments. Within sites, this response could be statistically analyzed only between the nil (no ripping) and ripping (only) treatments at Epping Forest, which showed that, without mounding, ripping reduced mortality from 40% to 4%, increased tree height from 126 cm to191 cm, and increased tree diameter from 37 mm to 54 mm (Figs. 7-9). Although the effects of ripping in the presence of mounding appeared also to be positive and significant, they were not as great as without mounding and interpretations were confounded by a lack of randomization. Also at Epping Forest there was a suggestion that mounding reduced mortality, but it did not affect the growth of survivors. These results are in general agreement with the literature that some form of cultivation benefits tree survival and growth, but this has not been shown previously for *P. radiata* on such dry sites, and importantly results generally support the assertion that ripping should accompany mound-ploughing of dry, ex-pasture sites.

Ripping appeared to be beneficial at three of the four sites, and we suspect that the benefit was derived from a combination of improved weed control and reduced soil strength aiding root development, but we did not attempt to identify the salient mechanism. Our results suggest that some ex-pasture soils may have a compaction problem that is at least partly alleviated by ripping. However, deep ripping of sites moderately compacted by forest harvesting did not benefit the first 2 years of *P. radiata* growth at one site in NSW (Lacey and Ryan 2000) and, when *Eucalyptus pilularis* was established on an ex-pasture site in the same state, when performed in conjunction with mounding, ripping beyond 40-60 cm depth was not needed (Lacey *et al.* 2001). That ripping was beneficial in our experiments is in contrast to the general lack of effect on eucalypt plantations of ripping ex-forest sites in higher rainfall zones (Holz et al. 1999) and ex-pasture sites in Victoria in similar rainfall zones to those we tested (Bird *et al.* 2000, Measki *et al.* 1998).

Because our results generally support the use of deep ripping (in combination with mound ploughing) on these ex-pasture sites, ripping to 60-70 cm depth should be encouraged in cultivation prescriptions for other plantations established on these types of sites.

Fertilization

The lack of any positive effect of fertilizing with DAP or KCl on two contrasting soil types (at Ouse) is not surprising, because ex-pasture sites are generally more fertile than ex-forest sites and likely to be in excess of the requirements of a new plantation (Skinner and Attiwill 1981, Wang et al. 1996, Osborne et al. 2001, Moroni et al. 2002). Not only is some or all of the fertilizer wasted when applied to sites that are already fertile, there is a risk of increased mortality if the fertilizer is placed too close to the seedling either deliberately or inadvertently. This risk was clearly demonstrated for K fertilization on a sand at Ouse (Fig. 16). Under these conditions, increased mortality resulted from the 15-20 cm surface-placement, which has been used recently as a guideline for K fertilizer application and was developed from experience on a soil with higher clay content (Smethurst and Appleton 19999), whereas mortality was not significantly affected by 25-30 cm surface-placement. Hence, as a precaution, the guideline for KCl placement on sands should be increased to 25-30 cm.

Three measures of P availability previously evaluated for eucalypts in the CRC (Mendham et al. 2002) were used to assess the P status of these sites, i.e. total P, Colwell P, and $CaCl_2$-P. However, the interpretations could only be tentative, because they were based on the sampling of only one soil profile at each site. Of these analyses, $CaCl_2$-P was most useful for eucalypt plantations. The Ouse Clay and Ouse Sand surface soils had concentrations of Colwell and total P that were very low and well within the range where one would expect a response to P fertilizer by eucalypts during the first year after planting. Concentrations of Colwell P at Ouse Clay and Ouse Sand were even very low compared to critical concentrations for pastures (Moody and Boland 1999). In contrast, $CaCl_2$-P concentrations were very high and well within the adequate range for eucalypts. There was no positive response to DAP fertilizer at these sites and these pine plantations grew well and exhibited no P deficiency symptoms. This result indicates that these sites were not P deficient for *P. radiata*, that $CaCl_2$-P may be a better indicator of P availability that the other two P analyses used, and that the critical concentration of $CaCl_2$-P under these conditions is less than 2.6 μM.

Total N, P and C have been calibrated as indicators of N deficiency in eucalypt plantations (Smethurst et al. 2003), and concentrations at Ouse Clay and Ouse Sand were well with the deficient range, yet there was no positive response to DAP fertilizer at these sites. Hence, N availability was apparently adequate during the first 2 years after planting under these conditions, but N deficiency might be expected to develop during subsequent years. Factors contributing to this apparent inconsistency are that the generally dry sites and drought conditions would have reduced growth and N demand, pines have a lower demand for N than eucalypts due to differences in growth rates, and N availability is often enhanced by establishment practices that stimulate N mineralization and reduce N uptake by competing vegetation. These results highlight the uncertainty about managing N on these types of sites and lead to the suggestion that research is warranted to refine N management practices on these types of sites so that profitability can be maximized.

We don't yet have adequate guidelines for assessing soil K availability in pine plantations, yet we know that *P. radiata* plantations are likely to be severely K deficient when established on some ex-pasture sites in Tasmania (Smethurst et al. 2001) and Gippsland, Victoria (Raupach and Hall 1974). Because there was no positive response to K fertilization, availability of K was apparently adequate at the Ouse Clay and Ouse Sand sites, and which was consistent with the observation that the concentrations of soil exchangeable K were not as low as in soils used for *P radiata* in Gippsland that are commonly K deficient (Raupach and Hall 1974, Turvey and Smethurst 1994). Concentrations of exchangeable K at Ouse Clay and Ouse Sand were also adequate when compared to critical concentrations for pastures and a range of agricultural crops (Gourley 1999).

These results support the current guideline that site fertility should be assessed with reliable criteria before prescribing fertilizer, that these criteria still need to be refined for pine plantations, and that many ex-pasture sites will have adequate N, P and K availability during the first 2 years of growth of a *P. radiata* plantation.

Weed Control

It was surprising that weed control did not improve growth at Ouse Clay and Ouse Sand, as it did at Pipers and has been demonstrated on many ex-pasture sites with pine and eucalypt plantations (Adams et al. 2003, Fremlin and Misic 1999, Mendham et al. 1999). The contrasting result at Ouse may have been related to the general dry nature of the site or the drought, which would have impeded weed growth, and there may have been an interaction with the timing of mound ploughing that minimized weed competition regardless of chemical weed control. These results suggest there is scope for decreasing weed control inputs at some dry, ex-pasture sites during the first year, but it would be unwise to change the general guideline that good weed control practices requiring chemical control are needed during plantation establishment. We are currently evaluating the need for weed control during years 1-3 after planting *P. radiata* at another dry site in Tasmania, and early results indicate substantial benefits of weed control during this phase of crop development (Smethurst pers. comm.).

Conclusions

1. Ripping, in the absence of mounding, positively affected tree survival and growth at Epping Forest.
2. At Epping Forest, Ouse Clay and Ouse Sand, ripping with mound-ploughing appeared to benefit tree survival and growth, but this was not confirmed statistically.
3. At Pipers, ripping with mound-ploughing did not affect tree survival or growth.
4. Fertilizers, which were tested only at the Ouse sites, were not required for adequate survival and growth during the first year, which was generally within our expectations.
5. Fertilizing Ouse Sand with surface-applied KCl placed closer than 20 cm from the seedling increased mortality.
6. There was a weak indication that DAP surface-applied closer than 5 cm also included a risk of mortality.
7. Weed control was beneficial at Pipers, but not at Ouse Clay or Ouse Sand.

Recommendations

1. Deep rip (70 cm depth) dry, ex-pasture sites whether mound-ploughing or not.
2. Dry, ex-pasture sites are likely to have adequate N, P and K fertility for the first year or two after planting.

3. Later applications of N and K may be necessary.
4. Base the assessment of soil fertility on fertilizer history of a site, local experience, and the use soil and foliar analyses in conjunction with reliable critical concentrations as they become available.

Research Needs Identified

1. Determine the relationship between the extent of ripping (vertically and horizontally) and tree growth on dry, ex-pasture sites, and the salient mechanisms involved.
2. Refine the critical soil and foliar nutrient concentrations for *P. radiata* established on dry, ex-pasture sites.

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