Establishment Techniques and Early Growth of Eucalypt Seedlings on a High Elevation Grass Site in Tasmania

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Abstract

The effects of various establishment techniques on early growth and survival of Eucalyptus nitens *and* E. delegatensis *were evaluated on a high altitude (870 m)* Poa *grass site in northern Tasmania. The most successful cultivation treatment was scalping (to remove grass) and ripping to a depth of 500 mm. Fertilizing with nitrogen and phosphorus at 25 and 11 grams elemental per tree respectively produced a large growth response. Weed control with amitrole at 1.5 kg a.i./ha and atrazine at 4 kg a.i./ha, applied pre-planting, produced a significant growth response and controlled* Poa *grasses for at least five years when combined with good cultivation. For* E. nitens, *small container stock grew as well as larger open-root stock. For* E. delegatensis, *open-root stock had much better early survival than container stock. However, by age five, both stock types had substantial mortality.*

With the best combination of treatments, E. nitens *survived satisfactorily, although its growth was very slow. At best, tree heights were 3.7 m at age five years, and total stem volume was about 7 m^3/ha.* Eucalyptus delegatensis *did not survive on this site, even with the best combination of establishment techniques.*

Introduction

Information on plantation establishment techniques on high elevation *Poa* grass sites in Tasmania is needed for two reasons. Firstly, increasing demand for plantation land has forced managers to consider using sites such as these. Secondly, past clearfalling of some high altitude *E. delegatensis* forests has created problems in regenerating these areas by re-seeding. Re-establishing these sites using seedlings is sometimes seen as a solution.

The importance of weed control, cultivation and adequate nutrition for successful eucalypt plantation establishment has been demonstrated in many field trials (e.g. McKimm and Flinn 1979; Fagg 1988; Wilkinson and Neilsen 1990; Neilsen and Wilkinson 1991). On high altitude grass sites, use of appropriate establishment techniques is especially critical. Studies on 'growth check' of *E. delegatensis* seedlings found limiting factors to be grass competition, inadequate nutrition and low temperatures (Keenan and Candy 1983; Webb *et al.* 1983; Ellis *et al.* 1985). On high altitude grass sites in Victoria, species selection, cultivation and nitrogen fertilizer were the important factors in determining successful tree establishment (McKimm and Flinn 1979).

This trial aimed to define suitable establishment techniques and determine early growth rates of *E. nitens* and *E. delegatensis* on a high altitude *Poa* grass site in Tasmania. The effects of cultivation, weed control, fertilization and nursery stock type on the growth and survival of seedlings were evaluated. The effects of browsing animals, an important constraint on some sites, were excluded from this trial by fencing.

Methods

Site description

The trial site was located at Maggs Mountain, 47 km south-west of Deloraine in northern Tasmania (41° 45' S; 146° 10' E). The locality forms part of a high, flat to gently undulating plateau, and the trial was located on a flat plain at an altitude of 870 m above sea level. Soils are krasnozems derived from Jurassic dolerite. Stones and small boulders occur throughout the soil profile and the soil depth is in excess of one metre.

The climate is typified by very high rainfall and low temperatures. Snowfalls are common and may accumulate for a number of days. Using the program BIOCLIM (Busby 1986; Nix 1986), mean annual rainfall for the trial site was estimated as 2130 mm, with estimates of rainfall for the wettest month (July) being 260 mm and for the driest month (February) being 110 mm. Temperature data from Cradle Valley (914 m elevation), 25 km west of Maggs Mountain, give an indication of temperatures at the trial site. Mean monthly maximum and minimum temperatures are 16° C and 6° C repectively for February, and 5° C and 0° C for July. Light frosts (< 2° C) and heavy frosts (< 0° C) occurred on an average of 145 and 86 days per annum respectively. Frosts may occur in any month but are particularly frequent from May to October.

The site previously carried a tall, and relatively open, *E. delegatensis* forest with a predominant mean height of 41–55 m. The understorey contained *Poa* spp. (snow grass) together with several herbaceous and woody species. The site was clearfelled in 1976 and re-sown with *E. delegatensis* in 1977. However, this regeneration failed and despite subsequent re-sowing and enrichment planting, the site remained poorly stocked. The present trial was established in 1986. The site was cleared and windrowed using a D7-size bulldozer with a rake blade. Cultivation treatments were done with the same bulldozer. The area was fenced with a netting and electric fence to protect trees from browsing animals.

Treatments

The following treatments were included in this trial:

1. Cultivation (7 levels): no cultivation; disc; rip; rip plus mound; disc plus rip plus mound; scalp; scalp plus rip plus mound.
2. Weed control (2 levels): no herbicide; amitrole 1.5 kg a.i.(active ingredient)/ha plus atrazine 4 kg a.i./ha applied pre-planting.
3. Species: *E. nitens*; *E. delegatensis*.
4. Fertilizer (2 levels): no fertilizer; 235 g 11:5:0 NPK per tree, which contains ammonium sulphate (10.5% N) and superphosphate (4.8% P).
5. Seedling stock type (2 levels): Open-root stock (planted late August); paper-pot stock (planted early October).

'No cultivation' treatments were not totally undisturbed since clearing resulted in some ground scarification. However, disturbance was minimal and re-colonisation by grasses rapid. Planting was very difficult where there had been no cultivation. Discing was done with 600 mm Giant off-set discs and cultivation was obtained to a depth of 200 mm. Discing broke up tussocks and clods well, which resulted in good planting conditions. Ripping was done with a 600 mm ripper, and the effective ripping depth was 500–600 mm. Ripping alone gave a relatively narrow cultivation band. Mounding was done using 800 mm tandem off-set discs which created a mound about 150 mm high and resulted in good planting conditions. Scalping was done using the blade of a bulldozer to totally remove grass tussocks. This process also removed the top 6–8 cm of topsoil. Scalping alone did not provide good planting conditions. Cultivation treatments were done in May when the soil was wet and the effects of cultivation were not optimal, but still acceptable.

Seed for *E. nitens* was a routine collection from Toorongo provenance in Victoria,

Table 1. Analysis of variance for Eucalyptus nitens *and* E. delegatensis *tree heights at age five years.*

Source of variation		*E. nitens* height (cm)				*E. delegatensis* height (cm)			
	d.f.	Sum of squares	Mean square	Variance ratio	F prob	Sum of squares	Mean square	Variance ratio	F prob
Block	1	2 942	2 942	0.9	0.39	17 827	17 827	41.1	< 0.01
Cultivation	6	124 742	20 790	6.2	0.02	31 533	5 256	12.1	< 0.01
Residual	6	20 161	3 360			2 604	434		
Herbicide	1	70 702	70 702	21.0	< 0 .01	4 044	4 044	1.7	0.24
Cultivation x herbicide	6	26 364	4 394	1.3	0.37	14 617	2 436	1.0	0.50
Residual	7	23 609	3 373			17 165	2 452		
Stock type	1	13 116	13 116	2.8	0.11	40 166	40 166	21.7	< 0.01
Cultivation x stock type	6	13 306	2 218	0.5	0.82	10 049	1 675	0.9	0.51
Herbicide x stock type	1	2 546	2 546	0.5	0.47	35	35	0.0	0.89
Residual	20	94 685	4 734			37 035	1 852		
Fertilizer	1	87 026	87 026	33.3	< 0.01	326	326	0.2	0.67
Cultivation x fertilizer	6	22 144	3 691	1.4	0.23	5 290	882	0.5	0.81
Herbicide x fertilizer	1	1 889	1 889	0.7	0.40	656	656	0.4	0.55
Stock type x fertilizer	1	201	201	0.1	0.78	8 698	8 698	4.9	0.03
Residual	47	122 909	2 615			83 391	1 774		
Total	111	626 339				273 436			

and seed for *E. delegatensis* was a routine collection from the Maggs Mountain/ Borradaile region in Tasmania. Seedlings were raised at Perth Nursery in northern Tasmania. Open-root seedlings were planted in late August and the average height at planting was 350 mm. Paper-pot seedlings were planted in early October, and the average heights of *E. nitens* and *E. delegatensis* were 120 mm and 60 mm respectively. Conditions on both occasions were cold and wet. Spacing was 3 m between rows and 2 m within rows (1667 trees/ha). The herbicide treatment was applied pre-planting as a 1.5 m strip using a knapsack spray in July. The fertilizer treatment was applied as a spot application in December.

Design and measurements

Treatments were applied as a factorial with two replications. The trial design was a nested randomised complete block, with the order of nesting (largest to smallest plots) being blocks, cultivation, weed control, species, stock type and fertilizer. Plot size in the smallest stratum was a single row of 10 trees (3 m x 20 m) and, in the cultivation stratum, plot size was eight rows of 20 trees (24 m x 40 m).

Tree height was measured at planting and at ages one, two, three, four and five years. Survival and annual height increment were calculated. When calculating increments, negative values were assumed to be zero. Survival data were transformed using an arcsin square root transformation due to non-normality of data. Analyses of variance were used to test significance of differences and interactions between treatments. The structure of the model used in the analyses of variance is indicated in Table 1. Initial analyses found many interactions involving species, and so each species was analysed separately.

Results

Cultivation

Cultivation treatments provided the greatest response of all treatments for *E. nitens*

Table 2. Effects of cultivation treatments on tree height, annual height increment and survival of E. nitens.

	Age (yrs)	Cultivation treatments nil	disc	rip	rip mound	disc, rip, mound	scalp	scalp, rip, mound	LSD 0.05	Sig. of diff.
Height (cm)	1	29	36	35	37	34	36	39	4	0.01
	2	58	69	73	76	67	78	83	6	< 0.01
	3	97	117	120	126	118	132	147	14	< 0.01
	4	142	176	186	192	176	185	212	28	0.02
	5	174	213	262	255	233	247	284	50	0.02
Increment (cm)	1	8	12	12	12	10	13	15	4	0.06
	2	30	33	39	40	33	42	44	6	< 0.01
	3	39	48	47	50	52	54	64	11	0.03
	4	50	59	66	66	56	53	65	19	0.22
	5	34	46	76	63	58	62	72	29	0.11
Survival (%)*	1	89	88	93	93	97	86	90		0.13
	2	69	71	76	83	89	75	86		0.25
	3	65	70	74	82	88	73	84		0.12
	4	60	61	71	81	86	71	83		0.06
	5	53	57	68	78	81	70	81		0.10

* LSDs (least significant differences) are not presented since the analysis was done on transformed data.

and significantly improved height at all measurements (Tables 1, 2). At age five years, heights of the best cultivation treatments were 63% greater than those of the control. The effect of cultivation on annual height increment was not as strong, and although differences were apparent at all measurements, they were not statistically significant after age three. Cultivation treatments had no significant effect on survival, but with increasing age, differences were becoming apparent (Table 2).

Cultivation treatments significantly improved height growth of *E. delegatensis*, although annual height increments were very small and not statistically significant (Tables 1, 3). Cultivation improved survival after the first year and the effects became increasingly important with increasing age.

The most successful cultivation treatment for both species was scalping plus ripping plus mounding (Tables 2, 3). This treatment resulted in the best, or equal best, height and survival at all measurements. Scalping alone resulted in good growth until age two, but its effects seemed less pronounced thereafter (Table 2). Treatments involving ripping provided a significant response at all measurements for *E. nitens* and, after age four (tree height of about 2 m), the effects became more pronounced (Table 2). Mounding, however, did not appear to provide any additional benefit (compare rip, and rip plus mound). Treatments involving discing were the least successful and re-invasion by grasses occurred more rapidly than with other treatments. Observations suggest part of the cultivation effect may be due to better grass control. At age five, the most successful cultivation treatments had lower grass cover regardless of herbicide application.

Fertilization

Fertilizing *E. nitens* at establishment with nitrogen and phosphorus gave a large and significant growth response (Tables 1, 4). The fertilizer effect was the second largest after cultivation effects. At age five, heights of fertilized trees were 27% greater than those of unfertilized trees. Differences in annual height increments between fertilized and

Table 3. Effects of cultivation treatments on tree height, annual height increment and survival of E. delegatensis.

	Age (yrs)	Cultivation treatments							LSD 0.05	Sig. of diff.
		nil	disc	rip	rip mound	disc, rip, mound	scalp	scalp, rip, mound		
Height (cm)	1	21	24	23	23	26	26	25	3	0.07
	2	23	24	26	29	32	29	39	12	0.15
	3	21	21	29	29	39	34	46	9	< 0.01
	4	19	14	34	31	38	42	53	13	< 0.01
	5	15	7	28	36	27	44	62	18	< 0.01
Increment (cm)	1	3	6	4	4	6	6	6	3	0.25
	2	7	6	10	8	8	8	17	10	0.23
	3	4	3	7	5	8	5	13	6	0.06
	4	5	2	8	7	6	11	11	5	0.03
	5	4	1	6	7	2	5	11	10	0.33
Survival (%)*	1	58	60	60	64	76	63	72		0.26
	2	18	19	14	22	28	28	44		0.06
	3	15	14	12	16	26	27	31		0.02
	4	6	8	5	9	20	18	24		0.04
	5	1	3	3	4	9	13	21		< 0.01

* LSDs (least significant differences) are not presented since the analysis was done on transformed data.

unfertilized trees were still evident at five years. In the first year, increments of fertilized trees were twice those of unfertilized trees although increments of all trees were small. Increments in the second year were much greater, and on fertilized trees were 59% larger than on unfertilized trees. By age five, differences in height increment were still significant, but had steadily diminished to 23%.

Fertilizing *E. delegatensis* gave no useful response. Height increment was significantly greater in the first year and differences in height were significant until age three, although all differences were small and of no practical importance (Table 4). Fertilizing had no effect on survival of either species.

Weed control

Herbicide treatment significantly improved height growth of *E. nitens* at all measurements (Tables 1, 5). The effects of herbicide treatment were third in order of magnitude after cultivation and fertilizer effects. At age five, heights on herbicide treated plots were 19% greater than on those without herbicide treatment. Annual height increments were also consistently greater and showed no signs of diminishing with increasing age. Survival was not significantly affected by herbicide treatment. However, differences became apparent with increasing age. At age one, there was no difference in survival, but by age five, weed control treatments had 8% better survival (Table 5).

Herbicide treatment resulted in no useful growth response for *E. delegatensis* (Tables 1, 5). At age two, total height and annual height increment were significantly improved, but at all other measurements there was no significant effect. Survival was unaffected by weed control at all measurements.

Poa grasses appear slow to re-establish if initially well controlled, with effects for the best treatments lasting at least five years. The effectiveness of the herbicide treatment (amitrole at 1.5 kg a.i./ha plus atrazine at 4 kg a.i./ha applied pre-planting) in controlling *Poa* grass was dependent on cultivation treatment. At age five, plots which had herbicide treatment in combination with

Table 4. Effects of fertilization (235 g per tree of 11:5:0 NPK) on tree height, annual height increment and survival of E. nitens *and* E. delegatensis.

	Age (yrs)	*E. nitens* nil	*E. nitens* fertilization	*E. nitens* sig. of diff.	*E. delegatensis* nil	*E. delegatensis* fertilization	*E. delegatensis* sig. of diff.
Height (cm)	1	29	40	< 0.01	22	26	< 0.01
	2	58	86	< 0.01	25	33	0.01
	3	103	142	< 0.01	27	36	0.01
	4	159	204	< 0.01	30	37	0.34
	5	210	266	< 0.01	29	33	0.67
Increment (cm)	1	7	16	< 0.01	3	7	< 0.01
	2	29	46	< 0.01	8	10	0.37
	3	45	56	< 0.01	6	7	0.72
	4	56	62	0.09	8	6	0.64
	5	53	65	0.03	5	5	0.87
Survival (%)	1	90	91	0.90	63	66	0.49
	2	80	77	0.20	25	25	0.94
	3	77	75	0.25	19	21	0.34
	4	75	72	0.11	11	14	0.15
	5	70	69	0.22	7	9	0.26

Table 5. Effects of weed control (amitrole at 1.5 kg a.i./ha plus atrazine at 4 kg a.i./ha, applied pre-planting) on tree height, annual height increment and survival of E. nitens *and* E. delegatensis.

	Age (yrs)	*E. nitens* nil	*E. nitens* amitrole + atrazine	*E. nitens* sig. of diff.	*E. delegatensis* nil	*E. delegatensis* amitrole + atrazine	*E. delegatensis* sig. of diff.
Height (cm)	1	33	37	0.03	24	24	0.55
	2	66	78	0.01	25	33	0.04
	3	111	134	0.01	28	34	0.19
	4	164	198	< 0.01	30	36	0.33
	5	213	263	< 0.01	25	37	0.24
Increment (cm)	1	10	13	0.01	5	5	0.26
	2	33	41	0.02	6	12	0.02
	3	45	56	0.01	6	6	0.86
	4	53	64	0.04	6	8	0.51
	5	49	68	< 0.01	4	6	0.32
Survival (%)	1	91	91	0.93	64	65	0.67
	2	77	80	0.45	24	26	0.18
	3	74	78	0.41	19	21	0.20
	4	71	75	0.41	12	14	0.29
	5	66	74	0.08	6	10	0.19

scalping or disc plus rip plus mound still had low grass cover. Other cultivation treatments had higher grass cover, although some herbicide effect was still apparent. Both sprayed and unsprayed plots which had no cultivation had dense grass cover.

Table 6. Effects of stock type on tree height, annual height increment and survival of E. nitens *and* E. delegatensis.

	Age	*E. nitens*			*E. delegatensis*		
	(yrs)	paper-pot	open-root	sig. of diff.	paper-pot	open-root	sig. of diff.
Height (cm)	1	27	43	< 0.01	10	38	< 0.01
	2	63	81	< 0.01	10	47	< 0.01
	3	114	131	< 0.01	11	52	< 0.01
	4	170	192	0.01	10	56	< 0.01
	5	227	249	0.11	12	50	< 0.01
Increment (cm)	1	16	7	< 0.01	5	6	0.23
	2	36	39	0.10	6	12	0.03
	3	52	49	0.41	4	9	0.01
	4	56	62	0.14	4	10	< 0.01
	5	58	59	0.79	3	7	0.11
Survival (%)	1	90	92	0.59	31	98	< 0.01
	2	80	77	0.14	7	43	< 0.01
	3	78	74	0.21	4	36	< 0.01
	4	76	71	0.07	3	23	< 0.01
	5	72	67	0.06	2	14	< 0.01

Stock type

Open-root and paper-pot seedlings were planted at different times and therefore effects of stock types were confounded with effects of planting time. However, different planting times used for each stock type generally represent operational conditions, and so comparisons made between stock types here are considered valid. Minimum temperatures in August 1986 (when open-root stock was planted), in October 1986 (when container stock was planted), and in June 1987 (one year after planting) were -6.5°C, -3°C and -11°C respectively.

Differences between paper-pot and open-root seedlings of *E. nitens* were significant prior to age five, but differences were never more than 20 cm (Tables 1, 6). Stock-type effects were the least of the four main treatments, with open-rooted stock being only 10% greater than paper-pot stock at age five. During the first year, height increment of paper-pot stock was considerably greater than that of open-root stock. However, after age one, annual height increments were not significantly different. Open-root stock was observed to suffer some transplant shock, with 45% of seedlings losing at least one-third of leaves within six weeks of planting, whereas paper-pot stock suffered no transplant shock. This may explain differences in increment in the first year. Survival was not affected by stock type.

There were significant and obvious differences between growth and survival of paper-pot and open-root seedlings of *E. delegatensis* (Tables 1, 6). In the first year, paper-pot stock practically failed, with only 31% survival, whereas open-root stock had 98% survival. Open-root stock (with juvenile leaf form) was not observed to suffer any transplant shock whereas paper-pot stock (with seedling leaf form) suffered substantial foliage loss within three months of planting. After the second winter (minimum temperatures of -11°C), open-root stock had also suffered high mortality. Although neither stock type had any substantial growth increment, the growth of open-root stock was better at all measurements.

Treatments in combination

For *E. nitens*, the effects of cultivation, fertilization, herbicide, and stock-type treatments were additive. The best combination of all these treatments produced a large response in height growth. With no site preparation treatments, heights were 100 cm at age five, whereas with cultivation (scalp plus rip plus mound), herbicide, fertilizer, and open-root stock, heights were 374 cm— an increase of 270% (Figure 1; Photos 1, 2). Survival was similarly affected, with 40% survival when there was no site preparation and 90% survival with the best combination of treatments. There were no interactions between treatments (Table 1), which indicates that the individual effects of treatments in combination were no greater than when applied alone.

Additive effects were also present with *E. delegatensis*, although no combination of treatments resulted in satisfactory growth and survival. With no site preparation, survival was 0%, and with the best combination of treatments height and survival at age five were only 90 cm and 40% respectively (Figure 2). Even with the best combination of treatments there was no height increment at age five.

Discussion

Establishment techniques

This trial has demonstrated that it is necessary to cultivate, control grass and add nutrients to successfully establish *E. nitens* seedlings on high altitude grassland sites. However, *E. delegatensis* failed to survive even

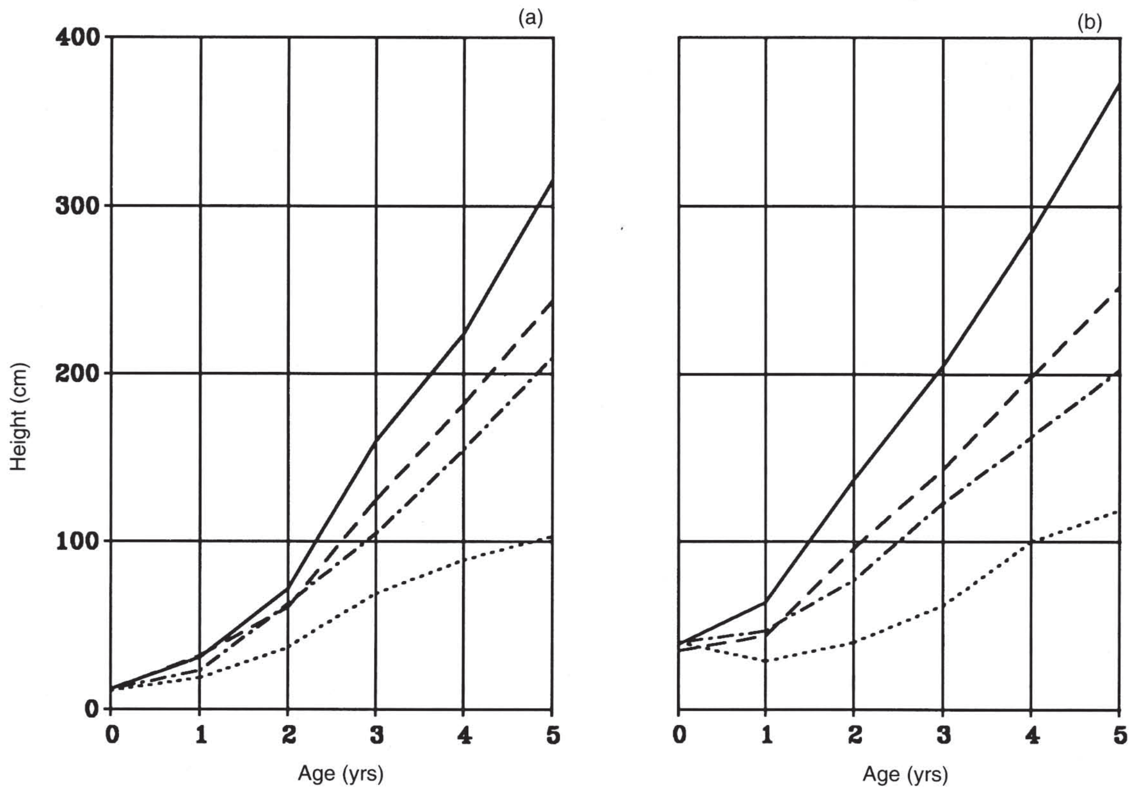

Figure 1. Height growth of E. nitens *with different establishment techniques (a = paper-pot, b = open-root).*

——— *Cultivation (scalp plus rip plus mound), weed control (amitrole plus atrazine), fertilizer (235 g 11:5:0 NPK).*
– – – – – *No cultivation, weed control (amitrole plus atrazine), fertilizer (235 g 11:5:0 NPK).*
– · – · – · *Cultivation (scalp plus rip plus mound), no weed control, no fertilizer.*
· · · · · · · *No cultivation, no weed control, no fertilizer.*

with the best combination of treatments. Other studies on similar sites have identified grass competition, slow mineralisation of nitrogen and low temperatures as the major constraints to seedling establishment (Ellis *et al.* 1985; McKimm and Flinn 1979; Webb *et al.* 1983). In addition, the importance of cultivation to maximise early growth has been demonstrated (McKimm and Flinn 1979). Although cultivation provided the greatest response of all main effects in this study, it is likely that an important part of the cultivation response was a response to persistent grass control.

Good grass control is probably the most important factor in plantation establishment on these sites. Dense grass has been shown to have a number of adverse effects on seedling growth. Firstly, it competes intensely for moisture. Small *E. delegatensis* seedlings were found to suffer substantial moisture stress when growing in dense grass (Webb *et al.* 1983). Secondly, it can cause nitrogen deficiencies. Grasses compete strongly for nitrogen and grasslands typically have low levels of mineral nitrogen and low rates of mineralisation (Ellis *et al.* 1985). *E. delegatensis* growing in grassland (including established trees over 1 m tall) were found to be deficient in nitrogen (Webb *et al.* 1983). Thirdly, a dense cover of grass reduces soil temperature. On a site at 920 m altitude in Tasmania, soil temperatures were found to be up to 5°C warmer on bare soil compared to soil covered by grass, and these temperature differences were thought to be important for root growth and increased

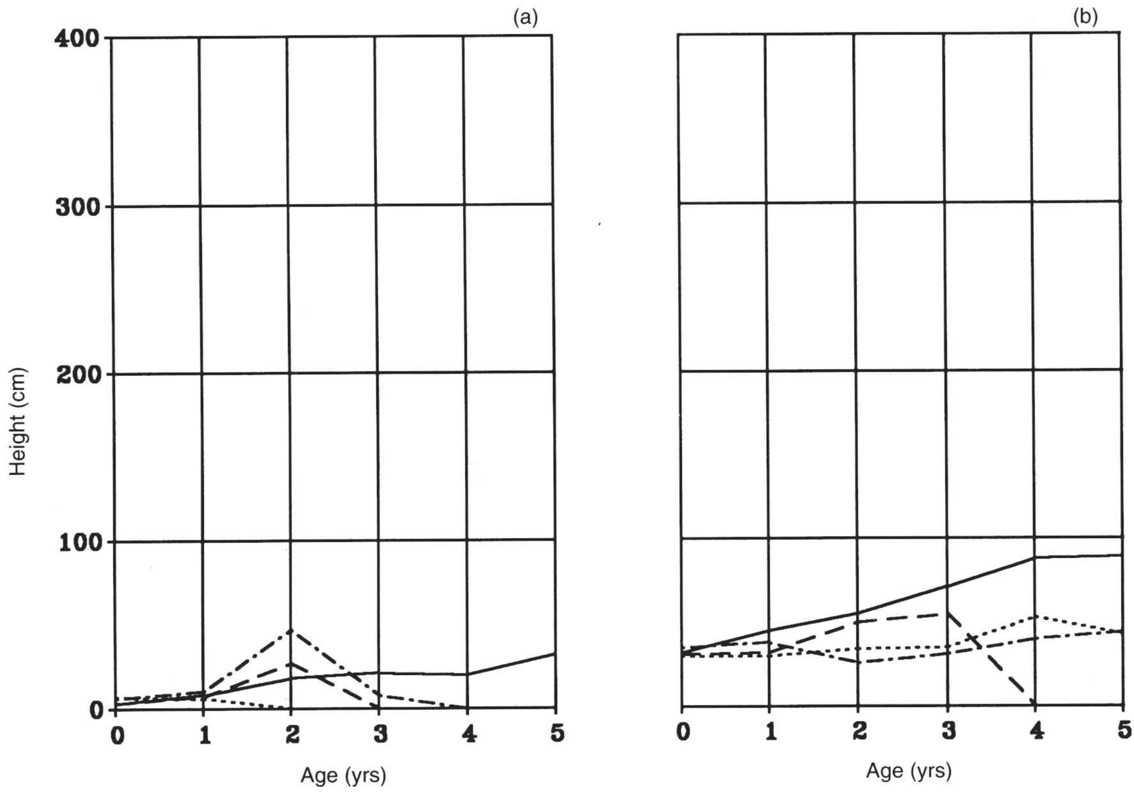

Figure 2. Height growth of E. delegatensis *with different establishment techniques (a = paper-pot, b = open-root).*

——— *Cultivation (scalp plus rip plus mound), weed control (amitrole plus atrazine), fertilizer (235 g 11:5:0 NPK).*
– – – – *No cultivation, weed control (amitrole plus atrazine), fertilizer (235 g 11:5:0 NPK).*
– · – · *Cultivation (scalp plus rip plus mound), no weed control, no fertilizer.*
· · · · · · · *No cultivation, no weed control, no fertilizer.*

rates of nitrogen mineralisation (Webb *et al.* 1983).

Cultivation would provide benefits other than reduced grass competition. Scalping, which mechanically removed all grass tussocks, provided a large growth response. Other studies on similar sites found manual weed control gave a greater growth response than chemical control (Ellis *et al.* 1985). This was thought to be due to removal of carbon which, if left, can immobilise plant nutrients. This process may explain part of the strong scalping effect. Ripping gave a significant growth response, presumably due to improved root penetration prior to re-invasion by grasses. Webb *et al.* (1983) noted that rapid root establishment of *E. delegatensis* is important if seedlings are to avoid grass competition. Part of the cultivation response could be due to improved planting conditions. Planting into uncultivated ground was found to be exceptionally difficult and seedlings, particularly open-root seedlings, were handled roughly in attempts to plant in these conditions.

Although nutrition of sites such as these is improved with grass control and cultivation (Ellis *et al.* 1985), addition of fertilizer provided a strong growth response on this, and on other similar sites. Studies on similar sites have recorded responses to nitrogen and not phosphorus (McKimm and Flinn 1979;

Photo 1. E. nitens, *age five years, established using no cultivation, weed control or fertilizer. Measuring stick in foreground is 1 m.*

Photo 2. E. nitens, *age five years, established with cultivation (scalp plus rip plus mound), weed control and fertilizer. Measuring stick in foreground is 1 m.*

Webb *et al.* 1983). Given the poor nitrogen status of high altitude grasslands (Ellis *et al.* 1985), the fertilizer response recorded on this site may also be a response to nitrogen only. The early growth response achieved from application of fertilizer would be important in successful establishment. It would allow trees to take best advantage of weed control and cultivation treatments, and may assist in avoiding very cold conditions at ground level. This would probably contribute to differences between fertilizer treatments still apparent five years after application.

Low temperatures encountered at high elevation sites are a major constraint to successful eucalypt establishment. Choice of stock type and planting time is one way to minimise effects of low temperatures during establishment. Open-root seedlings are hardier but must be planted in winter when dormant. Container stock can be planted later in the season although seedlings are generally less adapted to the field environment and, being smaller, are more likely to be affected by cold air at ground level. The choice must therefore be made between planting during extreme winter temperatures or using less robust stock. Although both open-root and paper-pot stock of *E. nitens* established successfully, it is unlikely paper-pot stock would survive if planted during the very cold months. For *E. nitens* seedlings, the frost resistance of unhardened container stock, hardened container stock, and fully hardened field stock is -3°C, -5.5°C and below -10°C respectively (Tibbits and Reid 1987). Minimum temperatures when open-root stock were planted (August 1986), when container stock were planted (October 1986), and in the winter following planting (June 1987) were -6.5°C, -3°C and -11°C respectively.

This trial was not subjected to the extremes of temperature that can be experienced on sites such as these. Bureau of Meteorology data suggest minimum temperatures in July–August and October–November can be as low as -13°C and -9°C respectively, and temperatures at the ground surface would be even lower. Severe damage to both open-root and container stock of *E. nitens* would be expected in these conditions.

This trial indicates open-root stock of *E. delegatensis* is much hardier than paper-pot stock, which suggests *E. delegatensis* is very susceptible to low temperatures when in the seedling leaf stage. However, even field hardened stock was not able to withstand minimum temperatures of -11°C in the following winter. In other studies, low temperatures have been a major limitation to *E. delegatensis* establishment, with temperatures of -4°C causing substantial mortality to hardened (container) seedlings and temperatures of -2°C causing damage to unhardened seedlings (Webb *et al.* 1983).

Growth rates

Growth of *E. nitens* was vastly improved when established using cultivation, weed control and extra nutrition (Figure 1; Photos 1, 2). Differences in height at five years were 1 m with no treatments compared to 3.7 m with the best combination of treatments. However, stem volume on the best plots was only 7 m^3/ha. These growth rates are exceptionally poor when compared to some other Tasmanian sites. At the same age and with similar establishment techniques, *E. nitens* was 11.5 m tall with a total stem volume of 82 m^3/ha on a granite site at an elevation of 120 m in north-eastern Tasmania, and 9.5 m tall with a total stem volume of 64 m^3/ha on a basalt site at an elevation of 600 m in north-western Tasmania (Forestry Commission, Tasmania, unpublished data). Clearly, sites such as those used in the present study are unsuitable plantation sites due to their very low productivity. Low temperatures are probably the major constraint to productivity on these sites.

Growth and survival of *E. delegatensis* was very poor even with the best combination of establishment techniques (Figure 2). A similar pattern of growth for *E. delegatensis* has been reported on sites such as these after clearfalling and regenerating native forest

(Keenan and Candy 1983; Webb *et al.* 1983; Ellis *et al.* 1985), and is referred to as 'growth check'. *Eucalyptus delegatensis* planted on a similar site in Victoria also failed (McKimm and Flinn 1979). It is difficult to predict long-term survival for *E. delegatensis*. Seedlings have been reported to commence more rapid growth after a period of five to 15 years in 'growth check' (Webb *et al.* 1983). However, even at its best, survival is too low to be considered successful and low temperatures remain a major constraint to *E. delegatensis* establishment on these sites. Establishing *E. delegatensis* on failed coupes using plantation techniques is therefore not likely to overcome difficulties encountered when re-seeding, and the same 'growth check' symptoms can be expected.

Conclusion

Eucalypt seedlings can be successfully established on high altitude *Poa* grass sites in Tasmania provided attention is given to the correct choice of species and establishment techniques. The most successful combination of treatments were cultivation by scalping and ripping, fertilizing with 235 g 11:5:0 NPK per tree, and grass control with amitrole at 1.5 kg a.i./ha and atrazine at 4 kg a.i./ha. Good cultivation combined with herbicide treatment gave grass control which was still evident at age five. Successful grass control is probably the most important objective in site establishment. Other studies have shown it can improve moisture availability, nutrition and soil temperatures. *Eucalyptus nitens* established successfully when planted using both open-root and container stock. Open-root stock of *E. delegatensis* was hardier although both stock types had very low survival. This trial was not subjected to the extremes of temperature possible on these sites, and both open-root and container stock of *E. nitens* would be expected to suffer damage in some years.

Although satisfactory survival of *E. nitens* can be achieved by attention to cultivation, adequate nutrition and grass control, growth rates remain very slow. At best, tree heights were 3.7 m at age five, and total stem volume was about 7 m^3/ha. Low temperatures are the primary limitation to tree growth on these sites. *Eucalyptus delegatensis* did not survive on this site, and its failure can be attributed to low temperatures. Even with cultivation, grass control, additional nutrition and use of large open-root seedlings, *E. delegatensis* exhibited the 'growth check' symptoms encountered in regenerated forests. Therefore, good plantation establishment techniques will not overcome problems encountered regenerating high altitude *E. delegatensis* on *Poa* grasslands.

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