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Establishment of trees on non-arable land to replace weeds

A report for the RIRDC/Land & Water Australia/FWPRDC
Joint Venture Agroforestry Program

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Foreword

The aim of this project was to investigate methods of establishing trees on non-arable land to replace weeds.

Some serious weeds (e.g. serrated tussock *Nassella trichotoma*, St. John's wort *Hypericum perforatum*, African lovegrass *Eragrostis curvula*) have infested steep rocky hill country where control by producers using pastures is unprofitable (Vere *et al.* 1993) and impractical. In Australia 900,000 ha of land is infested with serrated tussock and 400,000 ha with St. John's wort; 65% of this land is non-arable. New methods of control need to be found in these situations and the use of trees is one of the few remaining control methods available.

This project investigated the use of aerial seeding and direct drilling as cheap methods of establishing trees so that large areas could be controlled quickly and at relatively low cost ($549 to $1450 for aerial sowing and direct drilling readily available tree species, compared to from $1500 to $2200 for planting seedlings; see ***Cost of establishing trees***).

The following report describes the results of experiments set down over four years on steep and/or rocky land with the aim of establishing trees to control serrated tussock and St. John's wort.

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Executive Summary

Large areas of infertile hill country in low rainfall regions of Australia infested with weeds cannot be reclaimed by sowing pastures, because the pastures will not control the weeds and the process is unprofitable. One solution to this problem is to take this country out of production by sowing trees to control the weeds. The project reported in this publication, investigated low cost and rapid methods of establishing trees on non-arable land to control the weeds. The methods investigated were aerial sowing and direct drilling in contrast to the normal practice of planting seedlings.

Ten experiments were set down between 1995 and 1998 inclusive in two regions of NSW, ie, in the southern tablelands near Tuena and in the Monaro near Berridale. The following factors that influence establishment of trees were investigated: method of sowing; control of weed competition; time of sowing; species of tree; type of seedbed; pests and diseases; root additives; and weed control.

Results

In the experiments carried out in this project, establishment, for at least one species per experiment, was successful from 70% of aerial sowings; 90% of direct drillings and 88 % of seedling plantings. The respective figure for the most successful single species in the experiments, *P. radiata*, was: 37%; 75%; and 50%. For aerial sowing and direct drilling successful establishment was defined as >1 tree $10m^{-2}$ and for planted seedlings was defined as >80% establishment.

Control of Competition

Although trees established in experiment 1 in unsprayed serrated tussock from aerial sowing, direct drilling and planted seedlings, a similar result was never achieved again. The density of these trees declined substantially over time due to competition from weeds and the dry summers of 1997/8 and 1998/9 and the dry autumn of 1998. For example, the loss of *E. viminalis* in experiment 1 in the 3.3 years after initial establishment meaned for aerial sowing and direct drilling was 74% on the nil herbicide treatment and 46% on the two-spray herbicide treatment: the respective loss with planted seedlings was 33% and 10%.

Aerial sowing and direct drilling

In all experiments weed control was the major factor on which success depended. The weeds that cause most losses were annuals that established with the trees and grew during the first spring. To control these annuals it was necessary to spraytop in spring and apply glyphosate (Roundup®) 1 to 2 weeks before sowing. Pre-emergence herbicides (eg Goal) were applied with the glyphosate just before sowing in two experiments without substantial assistance to tree establishment. These herbicides did not control weeds for long enough into the first spring to assist establishment. Both experiments were conducted under dry conditions which did not favour the pre-emergence herbicides. Under moist conditions pre-emergence herbicides could assist establishment, particularly of *P. radiata,* which tolerates the herbicides better than the eucalypts. Ideally a post-emergence herbicide would control weeds in the first spring and assist tree establishment but the post-emergence herbicides used in these experiments, whereas they did control annual weeds, had deleterious effect on the young (6 weeks old) tree seedlings. For post-emergence herbicides to be effective they will have to be applied at accurately at a critical rate. Again *P. radiata* is more likely to tolerate post-emergence herbicides than eucalypts.

Burning serrated tussock in early spring assisted establishment of eucalypts in two experiments in this project by reducing the amount of litter on the soil surface and the infestation of annual weeds. In most situations burning will have to be combined with herbicide treatments to provide a weed-free seedbed.

Tree seedlings that survived competition from spring weeds had to then withstand competition from perennial weeds in their first summer. As selective post-emergence herbicides had little effect on these weeds the trees had to be able to survive this competition through their own competitive ability. Drought tolerant species that survived summer competition were: *P. radiata, E. albens, E. blakelyii, E. melliodora,* and *E. polyanthemos.*

Fertilizer (superphosphate) was applied in experiment 1, but because it promoted legumes and reduced tree establishment it was not applied in any other experiment.

Planted Seedlings
Planted seedlings were able to compete with weeds far better that aerially sown or direct drilled seedlings and were more tolerant to pre- and post-emergence herbicides.

Time of Sowing

The experiments were sown in winter or soon after to take advantage of the high percentage probability of receiving effective rain. This is the accepted procedure for aerial sowing and direct drilling pastures and has been used successfully over the last 30 years.

Aerial Sowing and Direct Drilling
Results of the experiments showed that trees could establish in winter. Establishment from aerial sowing depended on wet conditions with no long dry periods in the month after germination. For example, higher establishment (32.8 trees $10m^{-2}$, mean of 5 species) was obtained from aerial sowing in July 1998 than from sowing in late May 1998 (1.2 trees $10m^{-2}$) because the former had 7 consecutive dry days in the month after germination compared to the latter which had 13 consecutive dry days in the month after germination; the respective amount of rainfall per month was 95 mm and 149 mm. Establishment from sowings in late winter is favoured by better control of annual weeds at that time.
Establishment from direct drilling was consistently higher in the experiments than from aerial sowing due to a more sustained moisture supply. The main factor that promoted establishment from direct drilling was a wide drill run, ie 5 to 10 cm of scalloped soil on each side of the sown seed. This reduced weed competition close to the establishing seedling.

Planted Seedlings
Establishment of planted seedlings was favoured by planting in early winter compared to late winter or spring because there was more time for roots to grow to depth before dry summers. For example, loss of seedlings in the 2.1 years after sowing in 1996, meaned for 11 species, was 18% from the June sowing compared to 57% from the August sowing.

Species

Aerial Sowing and Direct Drilling
Of the many species sown *P. radiata* was outstanding at both locations and from both methods of sowing. In experiment 3 the percentage establishment of viable seed of *P. radiata* from direct drilling was 60% compared to that of *E. viminalis, E. macarthurii* and *E. aggregata* of, respectively, 8.6%, 6.4% and 0.1%. Establishment from aerial seeding was generally much lower, ie, for the above species in experiment 3 respectively, 25%, 2.0%, 1.6%, and 0.2%. The establishment in this experiment was higher than in other experiments but because eucalypt seeds are so small a 1% establishment is quite acceptable from the sowing rates used in this project giving 13 and 33 trees $10m^{-2}$ for *E. viminalis* and *E. melliodora* respectively. For *P. radiata* a 5% establishment of viable seed would be acceptable because it would yield 10 trees $10m^{-2}$ from 8 kg ha^{-1} sown in this project.

Another advantage of *P. radiata* over eucalypts is that it is tolerant to pre- and post-emergence herbicides whereas eucalypts are quite sensitive. However a seedbed of dead plant litter is needed for establishment of aerial sown *P. radiata* and inoculation with mycorrhiza is needed for aerial sown and direct drilled seed.

Of the eucalypts the most promising species to establish from aerial sowing and direct drilling were: *E. viminalis, E. melliodora, E. camaldulensis* and *E. polyanthemos.* However, as long-term establishment will depend on species that can survive in hill country environments it will be best to sow those species providing they can be established by aerial sowing or direct drilling.

The wattle species failed to establish from aerial sowing but established well from direct drilling. *A. melanoxylon* was sown in the latter experiments in preference to *A. dealbata* because of the susceptibility of the latter to insects and diseases.

Planted Seedlings

P. radiata was also outstanding when planted as seedlings. On the Monaro, 2.3 years after sowing, it was the only species to establish in experiment 4 and in experiment 3 it had the highest establishment (66% meaned for the June and September sowings). Of the five experiments at Tuena where *P. radiata* was sown in comparison with other species, it had the highest establishment in three; in the other two experiments two-year old low-quality seedlings were sown.

Pests

Treatment of seed to reduce losses due to seed harvesting ants allowed aerially sown seed to establish.

In experiments 1 and 6 birds took some large seeds (*P. radiata, B. populneum)* on aerial and direct drilled treatments; in experiment 8 the birds dug up some direct drilled seeds of these species. Wire cages placed over half the treatments in experiment 6 showed that birds did not take seeds in that experiment; nor did birds take large seeds in the other experiments. Thus losses due to birds will depend on the bird species in the vicinity of the sown area

Root Additions

The mycorrhiza necessary for the establishment and survival of *P. radiata* could be supplied by inoculating the seed before sowing which would be preferable to supplying large amounts of litter from under established trees. This aspect of establishment needs further research. A similar position exists for the introduction of *Frankia* onto the roots of *C. cunninghamiana.*

Weed Control

The recommended density of *P. radiata* to control serrated tussock of one tree $10m^{-2}$ (Hans Porada, State Forests of NSW, personal communication) was realized in many of the treatments in the above experiments and with attention to the findings of this project could be attained reliably from direct drilling and planting seedlings and less reliably from aerial sowing.

A greater density of eucalypts or wattles than one $10m^{-2}$ is necessary to control serrated tussock. However, if animals are excluded from the sown area and burning is not practiced volunteer plants will control the weed in many situations. This occurred in all unburnt experiments (2, 4, 8, 10) in this project where some residual fertility was available for the volunteer plants to grow. Volunteers could be fostered by applying fertilizer once the trees had attained sufficient height to withstand competition for light.

Conclusions

This project has indicated in it’s short duration that it is possible to control weeds on hill country by sowing trees. Establishment from direct drilling and planting seedlings is more reliable than from aerial sowing at the present level of knowledge. But as the cost of establishing trees from aerial sowing is lower and the rate at which infested areas can be sown is higher, further research is necessary to improve the reliability of establishment from this method.

Landholders may be able to afford to establish trees on small areas of their properties but large scale plantings can only be funded by public intervention in the weed control process. Jones *et al.* (1999) have economically assessed this situation and have concluded that on low rainfall-low soil fertility country, the socially optimal control option for serrated tussock is to retire the land from agricultural production and re-vegetate it with trees.

Introduction

Some weeds infest large area of non-arable land in Australia and due to the fall in the ratio of prices paid by farmers to prices received the weeds cannot be profitably controlled by pasture improvement (Vere *et al.* 1993). Serrated tussock and St. John's wort are two of the most widespread weeds that fall into the above category. Under the present economic conditions producers can only provide token resistance, such as occasional spraying, in the fight to control the weeds. Spraying is only a short term control method and without the establishment of pastures the weeds re-infest. Establishing trees to control weeds is a long term control solution which will also preserve the environment. *Pinus radiata* has been used to control serrated tussock in NSW. The trees were established by conventional planting of seedlings. However by using aerial seeding or direct drilling large areas of weeds could be sown to trees quickly and relatively cheaply (see ***Cost of establishing trees***).
Thus experiments were set down in this project with the objective of comparing the effectiveness of establishing trees by aerial seeding, direct drilling and planting seedlings in controlling weeds on non-arable land.

Methodology

Two experimental sites were chosen in situations representative of the major areas of serrated tussock infestation in NSW. The first site, near Tuena, was representative of the central and southern tablelands where serrated tussock infests 201,00 ha of steep hill country with moderate rainfall (726 mm year^{-1}) and low to moderate soil fertility. The second site was representative of the Monaro where serrated tussock infests 107,000 ha of moderately steep land with low rainfall (457 mm year^{-1}) and moderate to low soil fertility. The Tuena site was 400 km north of the Monaro site. Results from these sites would cover almost all environment infested with serrated tussock in NSW.

One group of experiments was set down from 1995 to 1998 on the property of John Cook, "Bumbletop", Tuena, NSW, in steep hill country (400 m to 600 m altitude) 12 km north of Tuena in the far north of the southern tablelands. A second group was set down in 1996 on the properties of Peter Ivers, "Valley View", Berridale and Bernie Powers, "Dimboola", Dalgety on the Monaro. The two sites on the Monaro were 15 km apart. The soils were moderately acid with low levels of phosphorous (5 mg kg^{-1} , Bray No. 1) and aluminum (1.2% of total exchangeable cations). All sites were heavily infested with serrated tussock and the Tuena site lightly infested with St. John's wort.

The experiments examined the effects of time of sowing, burning, and pre- and post- emergence herbicides on the establishment of a number of tree species sown by aerial seeding, direct drilling and planting seedlings. The experimental philosophy involved at the Tuena site was to impose treatments in succeeding experiments which depended on the results of preceding experiments. The Monaro experiments examined the best technology available in another quite unique environment. The aim was to solve problems as they occurred with the long term aim of producing reliable technology for the establishment of trees in serrated tussock infested areas.

Liquid herbicides were applied with a hand-held pneumatic sprayer in 500 L ha^{-1} water. A surfactant was added to Roundup® at 0.5 L ha^{-1} but Frenock® was applied without a surfactant. Solid herbicides were applied by hand broadcast mixed with sand.

The tree seedlings were sown in small plots (generally 5 seedlings to 1x5 m). Aerial sown and direct drilled seed was hand distributed mixed with sand after treatment with permethrin, i.e. Coopex®, at 0.5 kg 100 kg^{-1} seed (Campbell and Glimour 1979), to reduce losses due to seed-harvesting ants. The aerial sown seed was sown on unploughed land and the direct drilled seed was sown into drill runs made with a mattock; *P. radiata* and wattle seeds were sown 25 cm deep but eucalypt seeds were sown on the soil surface. Eucalypt seeds were not covered with soil but *P. radiata* and wattle seeds were. The seedbeds of all direct drilled species was firmed by walking on the furrow after sowing. The percentage germination of seed of all species sown was ascertained in the laboratory so that establishment could be compared on the basis of the percentage of viable seed sown.

The species of trees sown in the experiments were those recommended by State Forestry personnel that should survive in the respective environments. Species growing on the experiment sites were also sown.

Mycorrhiza in litter gathered from under existing radiata pine trees was top-dressed on the soil surface of aerial and direct drilled radiata pine treatments at, respectively, 7 and 3.5 t dry matter ha^{-1}. Seedlings were planted by digging a hole 15 cm deep with a mattock, planting the seedling, firming the soil around the seedling and watering once, immediately after planting. Fertilizer was applied in experiment 1 (superphosphate at 200 kg ha^{-1}) but not in any other experiment.

All experiments were fenced to prevent stock, kangaroos and rabbits from gaining access. At the Tuena site rainfall was recorded by Ron Glasson on the adjoining property "The Junction", Tuena approximately 1 km from the experiments. On the Monaro rainfall was recorded on the properties where the experiments were located. A complete record of rainfall data is not presented as it would not be useful. However where rainfall has influenced results details are presented.

Experiment 1- 1995 - Tuena

Aim. To examine the effects of burning and spraying serrated tussock prior to sowing four species of trees by three different methods.

The site of this experiment was a gentle slope in a valley facing north at 400 m altitude. The rocky soil was of moderate fertility and had a pH ($CaCl_2$) of 5.2 with an available phosphorous level (Bray No.1) of 10.3 $\mu g\ g^{-1}$. The site was heavily infested with serrated tussock that had received no treatment prior to setting down the experiment.
The experiment had two burning treatments (unburnt, burnt) x 3 herbicide treatments (nil, one, two sprays) x 3 methods of sowing (aerial, direct drilling, planted seedlings). Four tree species (ribbon gum *Eucalyptus viminalis,* silver wattle *Acacia dealbata,* river oak *Casuarina cunninghamiana* and radiata pine *Pinus radiata*) were sown on each plot. Serrated tussock was burnt on 6 June 1995 after nil, one spray (on 24 November 1994) or two sprays (24 November 1994, 23 May 1995). The November 1994 spray to kill serrated tussock and St. John's wort was a mixture of flupropanate (Frenock®) at 2 L ha^{-1} product (75% a.i.) and glyphosate (Roundup CT®) at 4 L ha^{-1} product(45% a.i.) and the May 1995 spray to kill annual weeds was Roundup CT® at 2 L ha^{-1}.

Seeds and seedlings (10 x 5 m^{-2} sub-plot) were sown on 7 and 8 June 1995; seeds at the following rates (kg ha^{-1}): ribbon gum (2), silver wattle (3.6), river oak (2), radiata pine (8). The direct drilled furrow (8 cm wide x 3 cm deep) was dug with a mattock and soil firmed by walking on the furrow after seeds had been broadcast on the cultivated soil surface.

Plots (4 x 5 m with sub-plots 1 x 5 m) were in a randomized block design, blocked for burning and spraying, with four replications.

Results were recorded at various times after sowing by counting the number of trees 5 m^{-2} sub-plot and measuring their height.

Experiment 2 - 1996 - Tuena

Aim. Because of the successful establishment of trees from sowing in winter (June) in Exp. 1 further examination of sowing in winter was carried out in Exp. 2 by sowing in each month of winter and sowing an extended range of tree species on a much more difficult site than Exp. 1.

The site was a steep rocky hill (15^0 or 25% slope) at an altitude of 600 m with a northerly aspect. The soil was of low fertility, derived from slate. It had a pH ($CaCl_2$) of 4.0, an available phosphorous level of 15 mg kg^{-1} and exchangeable cations (Ca, Mg, K, Na, Al, cmol (+)/kg $BaCl_2$) of, respectively 8.7, 2.4, 0.7, 0.1, 0.1. Prior to treatment in May 1996 ground cover consisted of 41% bare (17% rocks, 14% scald, 10% soil), 30% serrated tussock litter (19% dead standing, 11% lying on the soil surface), 23% broadleaved plants and annuals and 6% native perennial grass (mostly redleg grass *Bothriochloa macra*). The paddock had been aerially sprayed with 1.7 L ha^{-1} product Frenock® in October 1995 to kill serrated tussock.

The treatments imposed were 3 times of sowing (12 June, 25 July, 29 August 1996) x 3 methods of sowing (aerial, direct drilling, planted seedlings) x 11 species (Table 5). Plots were sprayed with Roundup CT® at 2 L ha^{-1} product 7 days before sowing. The aerial sown and direct drilled seed was broadcast on the soil surface by hand. The direct drilled furrow (6 cm wide x 3 cm deep) was dug with a pick and the soil firmed by walking along the furrow after the seed was sown. Seed of the 9 eucalypts was sown at 2 kg ha^{-1} (seed + chaff), radiata pine at 8 kg ha^{-1} and silver wattle at 4 kg ha^{-1}.

Mycorrhiza in litter gathered from under existing radiata pine trees was topdressed on the soil surface of aerial and direct drilled radiata pine treatments at, respectively, 7 and 3.5 t dry matter ha^{-1}; the June and July sowings were topdressed on 12 August 1996 and the August sowing on 15 October 1996.

Plots (4 x 11 m) were in a randomized block design, blocked for time of sowing, with four replications. Species were sown in 11 sub plots (4 x 1 m) randomized within each plot.

Results were recorded at various intervals after sowing.

Experiment 3 -1996 - Monaro

Aim. To examine tree establishment in a drier environment than the Tuena environment. Species reported to be adapted to the dry environment of the Monaro were sown.

The site of this experiment (750 m altitude) was a gentle slope facing west with rocky soil of low fertility derived from slate. Frenock® was applied in October 1995 to kill serrated tussock and Roundup CT® was applied the day before sowing. The treatments imposed were, two times of sowing (21 June and 18 September 1996) x three methods of sowing (aerial, direct drilling, planted seedlings) x five species (*E. viminalis, E. macarthurii, E. aggregata, E. pauciflora, P. radiata*). For both the aerial and direct drilling treatments the rate of seed sown at each sowing was 2, 2, 2, 1.6, 8 kg ha^{-1} for, respectively the species listed above. Plots (4x5 m, with sub-plots 1x4 m for variety) were arranged in a randomized block design with four replications.

Results were recorded at various periods after sowing.

Experiment 4 - 1996 - Monaro

The site of this experiment (750 m altitude) was a gentle slope facing east with soil derived from granite of moderate fertility containing few rocks.

The treatments imposed were the same as experiment 3.

Experiment 5 - 1997 - Tuena

Aim. To examine the establishment of tree species which need a more favourable environment (deeper soil, less rock, less slope) than the species sown in Exp. 2.

The site was a gentle slope with an easterly aspect at an altitude of 450 m. The soil, of moderate fertility derived from slate, (pH 4.9, phosphorous 4.7) was deep relative to other experiments and had few rocks. The paddock had been aerially sprayed with 1.7 L ha^{-1} Frenock® in October 1996 to kill serrated tussock.

The treatments imposed were 2 burning treatments (burnt, unburnt) x 3 methods of sowing (aerial, direct drilling, planted seedlings) x 6 tree species (Tables 8). In an effort to eliminate all weed competition for establishing trees, plots were sprayed with Roundup CT®: at 1.5 L ha^{-1} on 25 October 1996 (to stop annuals seeding); at 2 L ha^{-1} on 26 March 1997 (to kill redleg grass); and at 1.5 L ha^{-1} on 14 August 1997 (to kill annuals). Plots were burnt on 17 July 1997 and seed and seedlings sown between 19 and 21 August 1997. Eucalypts (Table 8) were sown at 2 kg ha^{-1} (seed and chaff) and radiata pine at 8 kg ha^{-1}. The direct drill furrow was 15 cm wide by 3 cm deep.

Plots (2 x 5 m) were in a randomized block design, blocked for burning, with three replications. Species were sown in sub-plots (2 x 1 m) randomized within each plot.

Results were recorded at various intervals after sowing.

Experiment 6 - 1997 - Tuena

Aim. To examine the effects of a pre-emergence herbicide (atrazine) on the establishment of *P. radiata*. Eucalypts were not sown because they are not tolerant to atrazine.

The site was a steep slope facing west in a valley at an altitude of 450 m. The soil (pH 4.9, phosphorous 4.1) contained may rocks, was of low fertility and derived from slate. The paddock had been aerially sprayed with 1.7 L ha^{-1} Frenock® in October 1996 to kill serrated tussock.

The treatments imposed were 2 herbicide treatments (Roundup CT®, RoundupCT® + atrazine) x 3 methods of sowing (aerial, direct drilling, planted seedlings) x 1 species, radiata pine cv GF 19. A planned post-emergence treatment was not imposed because of dry condition after establishment in spring 1997. All treatments were sprayed with Roundup CT® at 1.0 L ha^{-1} on 15 November 1996 to kill seeds of annual grasses. The two pre-emergence herbicide treatments were applied on 29 August 1997 and seeds and seedlings sown between 3 and 12 September 1997. The direct drilled furrow was 15 cm wide x 3 cm deep.

Plots (2 x 4 m) were in a randomized block design with four replications.

Results were recorded at various intervals after sowing.

Experiment 7 - 1997 - Tuena

Aim. To examine tree establishment on a very difficult site where burning could be used to control weeds and prepare a seedbed.

The site was a steep slope facing north at an altitude of 450 m. The soil (pH 5.0, phosphorous 5.3) was rocky, of low fertility and derived from slate. The site had been burnt in October 1995 which reduced the seed production of annuals to low levels.

The treatments imposed were 3 herbicide treatments (nil, one on 4 December 1996, Frenock® + RoundupCT®, to kill serrated tussock and redleg grass and the other, Roundup CT®, on 14 August 1997 to kill annual weeds) x 2 burning treatments on 17 July 1997 (nil, burnt) x 2 methods of sowing (aerial, direct drilling). Seed of five tree species (Table 10) was sown on 15 August 1997; the eucalypt seed at 2 kg ha^{-1} and the radiata pine seed at 5.5 kg ha^{-1}.

Plots (2 x 5 m) were in a randomized block design with three replications. Species were sown in sub-plots (1 x 2 m) randomized within each plot.

Results were recorded at various intervals after sowing.

Experiment 8 - 1997 - Tuena

Aim. To examine the effects of pre- and post-emergence herbicides on tree establishment on a very difficult site with a similar weed population to Exp. 2 where establishment was severely reduced by annual weeds.

The site was on top of a rocky hill at 600 m altitude with a slight northerly aspect. The soil (pH 5.1, phosphorous 4.9) was of low fertility and derived from slate. The paddock had been aerially sprayed with Frenock® at 1.7 L ha^{-1} in October 1995 to kill serrated tussock.

The treatments imposed were 4 herbicides(Roundup CT®, Roundup + pre-emergence, Roundup + post-emergence, Roundup + pre-and post-emergence herbicides) x 3 methods of sowing (aerial, direct drilling, planted seedlings) x 6 tree species (Table 11). Roundup CT® was applied at 2 L ha^{-1} , the pre-emergence Goal® (oxyfluorfen, 24% a.i.) at 1 L ha^{-1} product, the post-emergence for radiata pine Forest Mix® (hexazinone 5% a.i. + atrazine 15% a.i.) at 10 kg ha^{-1}product and the post-emergence for eucalypts Eucmix® (terbacil 4% product + sulfometuron methyl 0.2% product) at 5 kg ha^{-1}product. The Roundup® and Roundup® + Goal® treatments were applied on 1 July 1997 and the post-emergence herbicides applied on 30 October 1997.

Seeds and seedlings were sown between 11 July to 15 July 1997. Eucalypts were sown at 4 kg ha^{-1} , radiata pine at 16 kg ha^{-1} , blackwood (*Acacia melanoxylon*) at 8 kg ha^{-1} and kurrajong (*Brachychiton populneum*) at 32 kg ha^{-1} . The direct drilled furrow was 15 cm wide. Eucalypts were sown on the surface but the other three species were sown 25 cm to 35 cm deep.

Plots were in a randomized block design with four replications. Species were sown in six sub-plots (4 x1 m) randomized within each plot.

Results were recorded at various intervals after sowing.

Experiment 9 - 1998 - Tuena

Aim. To test the effects of repeated burning of serrated tussock on a difficult site on tree establishment in late winter.

The site adjoined experiment 7, thus it had all the characteristics of that site.

The treatments imposed were 2 times of sowing (16 July 1998; 20 August 1998) x 2 burning treatments (burnt April 1997; unburnt) x 5 species (Table 12). The whole site was burnt in October 1995, sprayed with Frenock® on 4 December 1996 and sprayed with RoundupCT Xtra® at 4 L ha^{-1}on 3 July 1998. Seed of 4 eucalypts was sown at 4 kg ha^{-1} and seed of radiata pine was sown at 8 kg ha^{-1}.

Plots (4 x 5 m) were in randomized blocks with four replications. Species were sown in 5 (4 x 1 m) sub-plots randomized within each plot.

Results were recorded at various intervals after sowing.

Experiment 10 - 1998 - Tuena

Aim. To re-test the effects of post-emergence herbicides on a site similar to Exp. 7 where the dry spring and summer of 1997 masked any effects that post-emergence herbicides could have had on tree establishment.

The site of this experiment was 500m to the west of Exp. 7 and immediately below experiment 2 and thus it had all he characteristics of that site.

The treatments imposed were 2 times of sowing (27,28 May 1998; 27 to 31 August 1998) x 2 post-emergence herbicides (+ and - herbicide) x 3 methods of sowing (aerial, direct drilling, planted seedlings) x 14 species. Plots were sprayed with Roundup CT Extra® (49% a.i.) at 4 L ha^{-1} before sowing eucalypts at 4 kg ha^{-1} and radiata pine (GF 19) and blackwood wattle at 8 kg ha^{-1}. The post-emergence herbicides Forest Mix® and Eucmix® were applied on 29 September 1998 at 10 and 5 kg ha^{-1} respectively.

Plots (4 x 10 m) were in a randomized block design, blocked for time of sowing with four replications. Species were sown in sub-plots (4 x 1 m) randomised within each plot.

Results were recorded at various intervals after sowing.

Results

Experiment 1 - 1995

For aerially sown and direct drilled seeds, establishment of *E. viminalis* and *P. radiata* was initially higher from direct drilling than from aerial sowing but after 3.7 years the superiority of direct drilling had waned due to intense competition between trees in treatments with high density establishments (Table 1).

Burning assisted the establishment of *E. viminalis* but had no effect on the other species (Table 1).

Table 1. Experiment 1. Effect of method of sowing and burning of serrated tussock on establishment of trees 0.8, 2.2 and 3.7 years after sowing, meaned for the three herbicide treatments

Treatment Method of sowing	Burning	Establishment (No. of trees 10m^{-2})								
		E. viminalis			*A. dealbata*			*P. radiata*		
		0.8y	2.2 y	3.7 y	0.8 y	2.2 y	3.7 y	0.8 y	2.2 y	3.7 y
Direct	Burnt	67a	81a	27a	6a	7a	4a			6a
drilled	Unburnt	55ab	62a b	29a	2 a	2 a	2a	9bc 20a	9bc 17a	7a
Aerial	Burnt	38b	48b	23a	2a	3a	4a	2c	3c	2a
	Unburnt	19c	25c	11b	2a	4a	5a	4c	7c	4a

Means in columns not followed by a common letter differ significantly at P>0.05

Herbicide treatment assisted establishment more as time after sowing increased (Table 2); the unsprayed tussock competing strongly with the trees in the dry summer and autumn of 1997/98 (27% and 35% below average rainfall respectively)and dry summer of 1998/99 (69% below average). Seedlings of *P. radiata* from aerial sowing or direct drilling were yellowish and lacked vigour due to the absence of mycorrhiza on their roots. Many seedlings became healthy after six months to one year, provided they survived the waiting period and were able to contact the mycorrhiza.

Table 2. Experiment 1. Effect of herbicide treatments on establishment 0.8. 2.2 and 3.7 years after sowing meaned for method of sowing (aerial and direct drilling) and burning treatments.

Herbicide treatment	Establishment (Number of trees 10m^{-2})								
	0.8y	2.2y	3.7y	0.8y	2.2y	3.7y	0.8y	2.2y	3.7y
Nil	35b	41b	9b	4a	3a	3a	10a	10a	2b
One spray	42ab	56ab	29a	2a	3a	4a	5a	6a	6a
Two sprays	57a	64a	31a	2a	4a	4a	11a	11a	6a

Means in columns not followed by a common letter differ significantly at P>0.05

Herbicide treatments did not initially improve establishment of planted seedlings but after 3.7 years establishment was higher on the sprayed treatments than on the nil treatment for three of the four sown species (Table 3). The low establishment of *C. cunninghamiana* was due to the lack of *Frankia* on the roots of the planted seedlings, some trees taking three years before they became green and healthy.

Table 3. Experiment 1. Effect of herbicide treatment on establishment (%) of trees planted as seedlings 0.8, 2.2 and 3.7 years after sowing, meaned for burning treatments.

Herbicide treatment	Percentage establishment											
	E. viminalis			*A. dealbata*			*C. cunninghamiana*			*P. radiata*		
	0.8	2.2	3.7	0.8	2.2	3,7	0.8	2.2	3.7	0.8	2.2	3.7
Nil	99a	96a	77b	66b	56b	55b	87a	26ab	17b	99a	96a	95a
One spray	99a	95a	89a	66b	66a	62a	87a	16b	21b	97a	97a	99a
Two sprays	97a	96a	87a	76a	61ab	60ab	92a	32a	40a	96a	95a	95a

Means in columns not followed by a common letter differ significantly at P>0.05

Experiment 2- 1996

Time of sowing had no effect on the establishment of aerially sown seed but August was superior for direct drilled seeds (Table 4). This was probably a reflection of less weed competition on the August treatment due to a better herbicide result than on the June treatment.

Initially August was also most favourable for the planted seedlings but after 2.7 years June gave the highest establishment (Table 4). This result probably reflected the ability of the June seedlings to withstand the dry summers better than the August sowing due to the former having more time in winter in the year of establishment to grow roots to depth in moist soil.

Table 4. Experiment 2. Effect of time of sowing on establishment of direct drilled and planted seedlings 0.3, 0.6, 1.8 and 2.7 years after sowing, meaned for 11 species

Time of sowing	Establishment										
	Aerial sowing (10m^{-2})			Direct drilling (10m^{-1} drill run)				Planted seedlings (%)			
	0.6y	1.8y	2.7y	0.3y	0.6y	1.8y	2.7y	0.6y	1.0y	1.8y	2.7y
June	0.2	0.4	0.3	19b	1.3	0.7	0.6	49b	47b	36a	38a

	a	a	a		c	c	b				
July	0.1a	0.3a	0.4a	37a	4.6b	1.6b	1.4b	62a	57a	35a	36a
August	0.1a	0.4a	0.4a	36a	8.4a	3.6a	2.9a	61a	60a	27b	26b

Means in columns not followed by a common letter differ significantly at P>0.05

In the 2.7 years after sowing a high percentage of seedlings died on the direct drilled treatment due to dry summers and competition from annual weeds (Table 5). The species with highest survival were *E. camaldulensis* (22%), *A. dealbata* (16%) and *E. melliodora* (15%); other species had from 0% to 8% survival.

Survival of species planted as seedlings varied widely with *P. radiata* and *E. melliodora* recording highest survival (Table 5).

Table 5. Experiment 2. Establishment of tree species in the 2.7 years after sowing meaned for the three times of sowing

Species	Establishment						
	0.3y	0.6y	1.8y	2.7y	0.6y	1.8y	2.7y
E. viminalis	84a	15a	6.2a	4.2b	85ab	55b	54b
E. melliodora	42bc	10b	5.4ab	6.3a	83abc	71ab	73a
A. dealbata	14de	9b	4.2b	2.3c	ns	ns	ns
E. camaldulensis	16de	7bc	5.0ab	3.6bc	71bc	60b	60b
E. macarthurii	37c	4cd	0.8c	0.4d	68bc	17cd	23cd
P.radiata	18de	1d	0.2c	0.4d	94c	83a	81a
E. aggregata	47b	1d	0c	0d	62d	8cd	11cd
E. fastigata	41bc	2d	0c	0d	35c	8cd	8cd
E. mannifera	20d	4cd	0.4c	0.4d	62d	27c	25c
E. macrorhyncha	10ef	1d	0c	0d	23c	2d	4d
E. globulus	1f	0d	0c	0d	73abc	23c	21cd

Means in columns not followed by a common letter differ significantly at P>0.05
ns: not sown

Experiments 3 and 4 - 1996 - Monaro

Aerial Sowing and Direct Drilling: At both sites establishment was higher, with a few exceptions, from direct drilling than from aerial seeding and from the June sowing than from the September sowing (Table 6). Survival of trees over their first 2.3 years was higher, with one exception, from the June sowing than from the September sowing and survival was much higher at Berridale than at Dalgety (Table 6). The outstanding species for survival over the 2.3 years of the experiment was *P. radiata* for both aerial and direct drilling (Table 6).

Planted Seedlings: Establishment 2.3 years after sowing was higher from the June sowing than from the September sowing with the exception of *E. pauciflora* (Table 7). Establishment at the Berridale site was much higher than at the Dalgety site. Of the species sown *P. radiata* had the highest survival in three of the four treatments; it was the only species to survive after 2.3 years at Dalgety (Table 7).

Table 6 . Experiments 3 and 4. Effect of time (June and September 1996) and method of sowing on the establishment of trees at two sites on the Monaro measured 0.4 and
2.3 years after sowing.

Method	Time	Establishment (trees: 10m^{-2}, aerial; 10m^{-1} row, direct drilling)									
		E. viminalis		*E. macarthurii*		*E. aggregata*		*E. pauciflora*		*P. radiata*	
		0.4y	2.3y	0.4y	2.3y	0.4y	2.3y	0.4y	2.3y	0.4y	2.3y
						Berridale					
Direct	June	176a	10a	75a	4.4a	51a	1.9a	104a	0.6a	179a	14.4a
drilling	Sept	76b	4b	27b	0b	8b	0b	20b	2.5a	111b	8.1a
Aerial	June	40c	2b	19b	1.9a	11b	0b	1b	0b	76c	23.1a
	Sept	12d	0c	0c	0b	1b	0b	0b	0b	2d	0.6b
						Dalgety					
Direct	June	78a	0	34a	0	6a	0	24a	0	26b	0
drilling	Sept	21b	0	5b	0	0b	0	11b	0	53a	0
Aerial	June	1b	0	0c	0	0b	0	0c	0	1c	0
	Sept	0b	0	0c	0	0b	0	0c	0	0c	0

For each site, means in columns not followed by a common letter differ significantly at P.0.05.

Table 7. Experiments 3 and 4. Effect of time of sowing on establishment (%) of five species of trees planted as seedlings at two sites on the Monaro measured 0.4 and 2.3 years after sowing.

Time of sowing	Establishment (%)									
	E. viminalis		*E. macarthurii*		*E. aggregata*		*E. pauciflora*		*P. radiata*	
	0.4y	2.3y	0.4y	2.3y	0.4y	2.3y	0.4y	2.3y	0.4y	2.3y
					Berridale					
June	25	6	94a	62a	100a	69a	58b	31b	90a	81a
September	ns	ns	100	53a	100a		81a	69a	75b	50b

			a			56a				
					Dalgety					
June	8	0	75a	25a	92a	17a	75a	17a	92a	42a
September	ns	ns	83a	0b	92a	0b	83a	0b	100a	25b

For each site, means in columns not followed by a common letter differ significantly at P>0.05

Experiment - 5 - 1997

Aerial and Direct Drilling: Establishment was higher for all except one species from direct drilling than from aerial seeding in the 1.6 years after sowing (Table 8). The outstanding species were *P. radiata* and *E. melliodora* on the direct drilling treatment and *E. viminalis* and *E. melliodoa* on the aerial seeding treatment (Table 8).

Planted seedlings: The outstanding species for survival for the 1.6 years after sowing on the planted seedling treatment were *E. polyanthemos* and *E. albens* (Table 8).

Table 8. Experiment 5. Effect of method of sowing on establishment of trees in the 1.6 years(y) after sowing in August 1997, meaned for burning treatments.

Species	Establishment								
	Aerial ($10m^{-2}$)			Direct drilling ($10m^{-1}$ drill run)			Planted seedlings (%)		
	0.3y	0.8y	1.6y	0.3y	0.8y	1.6y	0.2y	0.8y	1.6y
E. viminalis	42a	2.1a	2.9a	110a	3.7b	2.9c	95a	50c	50c
E. melliodora	20b	2.1a	2.5a	87b	7.5a	7.1a	ns	ns	ns
E. albens	4c	0.4b	1.3b	24d	2.0c	2.9c	100a	75b	82b
E. globulus	2c	0c	0c	33d	1.1c	0.9d	97a	22d	22d
P. radiata	2c	0c	0c	52c	8.0a	5.4b	95a	64c	55c
E. polyanthemos	ns	ns	ns	ns	ns	ns	98a	100a	100a

Means in columns not followed by a common letter differ significantly at P>0.05
ns: not sown

Experiment 6 - 1997

As the pre-emergence herbicides had no significant effect in this experiment, due to the dearth of annual weeds on the site, the main results showed that direct drilling was again more successful than aerial seeding and that establishment of planted seedlings was acceptable (Table 9) despite the dry conditions in summer\autumn 1997/98 (35% below average rainfall).

Table 9. Experiment 6. Effect of method of sowing on establishment, aerial, (trees 10 m^{-2}); direct drilling, (trees $10m^{-1}$ drill run); seedlings, (% of seedlings sown) of *Pinus radiata* 0.2, 0.8 and 1.6 years after sowing in September 1997.

Method of sowing	Establishment

	0.2 years	0.8 years	1.6 years
Aerial sowing	2.1a	1.2b	1.2b
Direct drilling	42.0a	20.0b	8.7c
Seedlings	95.0a	88.0b	87.0b

Means in rows not followed by a common letter differ significantly at P>0.05

Experiment 7 - 1997

Initially (0.2 years after sowing) burning assisted the establishment of eucalypts but not *P. radiata* and herbicide treatments assisted all species. At 1.8 years after sowing only the effect of the herbicides was evident on the direct drilling treatments (nil 0, one spray 0.1, two sprays 2.5 trees $10m^{-2}$) (results not presented). Establishment from direct drilling was superior to that from aerial sowing at all times after sowing (Table 10).

Table 10. Experiment 7. Effect of method of sowing on establishment of five tree species sown on 17 August 1997 meaned for herbicide and burning treatments (1.8 years after sowing).

Species	Establishment (trees $10m^{-2}$ aerial; $10m^{-1}$ row, direct drilling)					
	Aerial			Direct drilling		
	0.2y	0.8y	1.8y	0.2y	0.8y	1.8y
E. viminalis	1.8a	0	0	21.7b	0.6b	0.6b
E. albens	0b	0	0	1.7c	0b	0b
E. mannifera	0b	0	0	4.7c	0.4b	0.4b
E. pauciflora	0b	0	0	4.8c	0b	0b
P. radiata	0.2b	0	0	55.0a	3.7a	3.1a

Means in columns not followed by a common letter differ significantly at P>0.05

Experiment 8 - 1997

In this experiment the pre- and post-emergence herbicides had little effect and thus the major difference in treatments was in the methods of sowing, direct drilling again being superior to aerial sowing (Table11). The low percentage establishment of planted seedlings was due to the difficult site and to the supply of low quality seedlings. For example, the *E. viminalis* and *A. melanoxylon* were tall, thin seedlings and the *P. radiata* were two years old with tops and roots trimmed.

Table 11. Experiment 8. Effect of method of sowing on establishment (Aerial, trees $10m^{-2}$; direct drilling, trees $10m^{-1}$ drill run; seedlings, % of seedlings sown) of six tree species, 0.2, 0.8 and 1.7 years after sowing in July 1997.

Species	Establishment								
	Aerial			Direct drilling			Planted seedlings		
	0.2y	0.8y	1.7y	0.2y	0.8y	1.7y	0.2y	0.8y	1.7y
E. viminalis	11.9 a	0.6a	0.3a	117.5a	8.9b	6.6b	100 a	52b	49b
E. albens	0b	0a	0a	11.2c	7.2b	5.9b	100 a	73a	74a
E. blakelyii	1.0b	0.6a	0.3a	3.7c	2.7c	2.8c	97a	89a	88a
P. radiata	0b	0a	0a	64.4 b	18.6 a	8.0ab	75b	33bc	31bc
A. melanoxylon	0b	0a	0a	58.7b	16.7 a	10.5a	80b	20c	21c
B. populneum	0b	0a	0a	2.5c		0d		80a	23c

		1.1c	92a

Means in columns followed by a common letter differ significantly at P>0.05

Experiment 9 - 1998

The main result from this experiment was the good establishment of aerial sown seed, the July sowing being superior to the August sowing (Table 12). Establishment was also good from direct drilling but in this case the August sowing was superior. Overall *P. radiata* gave the best establishment of all species sown.

Table 12. Experiment 9. Effect of time (July, August 1998) and method of sowing (aerial, direct drilling) on establishment of five tree species measured 0.3 years after sowing

Species	Establishment (trees: $10m^{-2}$, aerial; $10m^{-1}$ row, direct drilling)			
	Aerial		Direct drilling	
	16 July '98	20 August '98	16 July '98	20 August '98
P. radiata	55 cd[A]	19 ef	154 a	155 a
E. polyanthemos	20 ef	7 f	5 f	28 def
E. viminalis	53 de	4 f	31 def	102 b
E. melliodora	33 def	4 f	14 f	75 bc
E. sideroxylon	3 f	2 f	5 f	10 f
Mean	32.8 B[B]	7.2 C	41.8 B	74.0 A

[A] Means in columns not followed by a common lower case letter and [B]means in row not followed by an upper case letter differ significantly at P<0.05

Experiment 10 - 1998

Establishment from direct drilling was superior to that from aerial sowing and the August sowing on the direct drilling treatment was superior to the July sowing for all but one species (Table 13). Time of sowing only had minor influences on the establishment of planted seedlings. There were large differences between species for direct drilling and smaller differences between species for planted seedlings.

Post-emergence herbicides appeared to depress establishment slightly but measurements were taken too soon after sowing (4 months) to be able to form a firm opinion (Table 14).

Table 13. Experiment 10. Effect of time (May, August 1998) and method of sowing (Aerial, direct drilling, planted seedlings) on establishment of seven tree species meaned for post-emergence herbicide treatments measured 0.3 years after sowing

Species	Establishment (trees: aerial,$10m^{-2}$: direct drilling, 10^{-1} drill run; seedlings, %)					
	Aerial		Direct drilling		Planted seedlings	
	May	August	May	August	May	August
A. melanoxylon	0	0	279.7a	142.7a	66bc	60bc
P. radiata	7.8a	0.3	66.0b	106.3b	97a	84a
E. viminalis	0	0	1.9c	36.3cd	78b	62bc
E. albens	0.3b	0	4.1c	25.0de	100a	86a
E. macarthurii	0	0	0.3c	16.3de	56c	52c
E. melliodora	0	0	0.3c	14.0e	97a	82a
E. camaldulensis	0	0	0	8.5ce	76b	75ab

Mean all Spp.	1.2A	0.04A	50.3A	49.9A	81A	72A
Mean eucalypts	0.06	0	1.3B	20.0A	81A	71A

Means in columns not followed by a common letter differ significantly at P>0.05
Means for all Spp. and eucalypts when compared for May and August sowings are not significantly different at P>0.05, except for direct drilled eucalypts.

Table 14. Experiment 10. Effect of post-emergence herbicides (-,+) on establishment of seven tree species sown by aerial, direct drilling and planted seedlings, meaned for time of sowing

Species	Establishment (trees: aerial 10^{-2} ; direct drilling, 10^{-1} drill run; seedlings %)					
	Aerial		Direct drilling		Planted seedlings	
	-	+	-	+	-	+
A. melanoxylon	0b	0b	227.5a	195.0a	72de	53d
P. radiata	2.3a	7.0a	103.0b	69.5b	88bc	94a
E. viminalis	0b	0b	21.5c	16.5c	75cd	66c
E. albens	0b	0.3b	16.5c	12.5c	100a	93a
E. macarthurii	0b	0b	10.8c	6.0c	59e	51d
E. melliodora	0b	0b	9.0c	5.3c	97ab	82ab
E. camaldulensis	0b	0b	6.3c	2.3c	78cd	73bc
Mean, all Spp.	0.32	1.04	56.4	43.8	81	73
Mean, eucalypts	0	0.06	12.9	8.5	82	73

Means in columns not followed by a common letter differ significantly at P>0.05
Means for all Spp. and eucalypts when compared for May and August sowings are not significantly different at P>0.05.

Discussion

Of the experiments carried out in this project, establishment, for at least one species per experiment, could be described as “successful” from: 70% of aerial sowings, 90% of direct drillings and 88% of seedling plantings (Table 15), depending on the definition of “successful” used. For aerial sowing and direct drilling successful establishment was defined as >1 tree $10m^{-2}$ and for planted seedlings successful establishment was defined as >80%.

Table 15. Summary of effect of method of sowing on establishment of trees for all experiments, from 1995 to 1998 inclusive. Figures are only given for species that achieved some establishment.

Experiment	Establishment (trees: $10m^{-2}$, aerial; $10m^{-1}$ drill run, direct drilling; %, planted seedlings) Aerial	Direct drilling	Planted seedlings
1 1995 - Tuena	11.0 - 23.0	27.0 - 29.0	95 - 99
2 1996 - Tuena	0.3 - 0.4	0.4 - 6.3	4 - 81
3 1997 - Monaro	1.9 - 23.1	2.5 - 14.4	25 - 81
4 1997 - Monaro	0	0	25
5 1997 - Tuena	1.3 - 2.9	0.9 - 5.4	22 - 100
6 1997 - Tuena	1.2	8.7	87
7 1997 - Tuena	0.2 - 1.8	0.4 - 7.5	not sown
8 1997 - Tuena	0.3	2.8 - 10.5	21 - 88
9 1998 - Tuena	2.0 - 55.0	5.0 - 155.0	not sown
10 1998 - Tuena	0.3 - 7.8	0.3 - 280.0	52 - 100

To obtain another overveiw of all experiments in this project the establishment of the two species sown in all experiments (*P. radiata* and *E. viminalis*) can be compared under standard conditions (Table 16). The results of this appraisal (Campbell and Dowling 1999) show that the percentage of successful sowings for each method of sowing was lower than when considering all species sown (Table 15). This conclusion suggests that sowing a mixture of species would increase the chance of successful establishment. However sowing a mixture of species could only be undertaken where country was being retired from production of pasture, timber or other tree products and being aforrested solely for the control of weeds.

Table 16. Summary of effect of method of sowing on establishment of *E. viminalis* and *P. radiata* in experiments where seeds and seedlings were sown in winter into unburnt serrated tussock after one herbicide treatment to kill weeds

Experiment	Years after sowing	Establishment of trees from: Aerial sowing (trees $10m^{-2}$)		Direct drilling (trees 10 m^{-1} drill run)		Planting seedlings (% establishment)	
		E. viminalis	*P. radiata*	*E. viminalis*	*P. radiata*	*E. viminalis*	*P. radiata*
1. 1995 -Tuena	3.7	13.0	6.5	59.5	13.5	90	100
2. 1996 - Tuena	2.7	0.4	0.2	4.2	0.4	54	81
3. 1996-Monaro	2.3	1.9	23.1	10.0	14.4	6	81
4. 1996 - Monaro	2.3	0.0	0.0	0.0	0.0	0	42
5. 1997 - Tuena	1.6	2.9	0.0	2.9	5.4	50	55
6. 1997 - Tuena	1.7	0.3	0.0	6.6	8.0	49	31

7. 1998 - Tuena	0.8	6.3	3.5	7.2	32.0	not sown	not sown
8. 1998 - Tuena	0.7	0.0	0.3	2.8	13.8	70	91
% successful sowings		50	37	87	75	12	50

The major factors necessary for successful establishment of trees in these experiments appeared to be: time of sowing; control of competition; tree species; seedbed; and root additions.

Time of Sowing

The experiments were sown in winter or just after to take advantage of the high percentage probability of receiving effective rain in winter (98% in June; 97% in July and 95% in August). The accepted method of establishing pastures from aerial sowing and direct drilling has been to sow the seed in winter (Campbell 1963; Campbell *et al.* 1966) and this practice has been in practical operation in NSW for the past 30 years.

Aerial Sowing and Direct Drilling: Results of the experiments showed that trees could establish in winter from aerial sowing (eg experiments 1, 3, 9) and direct drilling (eg experiments 1, 3, 6, 8, 9, 10).

Establishment from aerial sowing depended on obtaining rain over a period of a month after sowing with no long dry periods. For example, higher establishment was obtained in 1998 from sowing in July (experiment 9) than from sowing in late May (experiment 10) because the former had 7 consecutive dry day during the month of establishment compared to the latter with13 consecutive dry days in the month; the respective amount of rainfall was 95 mm and 149 mm. The critical period in establishment of aerially sown seed is during radicle entry into the soil. If the radicle tip dries out then the seedling will die. Radicle tips die in four hours of dry conditions at 25^0C but will remain alive for much longer periods at the lower temperatures of winter. However long dry periods in winter will kill the tip and cause failure in establishment. Dry conditions are most deleterious where seeds are sown on bare rocky ground and where weed competition exists. The site of experiment 7 was particularly harsh which influenced the low establishment from the August sowing.

Establishment from direct drilling is less subject to dry conditions during the early establishment phase and thus establishment is generally more reliable and of higher density than aerial sowing (Table 15). Factors that assisted the success of direct drilling were a wide drill run (10 - 20 cm) to reduce weed competition close to the establishing seedlings, planting large seeds 2.5 cm below the soil surface, sowing small seeds (eucalypts) on the soil surface and compacting the drill run after sowing.

A result evident later in the reseach project was the interaction of time of sowing and contol of weed competition on establishment. Applying herbicides towards the end of winter or in early spring gave better control of annual weeds than did spraying earlier in winter and this resulted in higher establishment of aerial sown and direct drilled trees. Because weed control appears to be the major factor limiting establishment of trees then sowing should take place at the above time despite higher evaporation and thus less favourable moisture conditions than earlier in winter. Under these drier conditions aerial sowing would be at a greater risk than direct drilling.

Planted Seedlings: Establishment of planted seedling was favoured by planting in early winter compared with late winter or spring because there was more time for roots to grow to depth before dry summers. Results from experiment 2 demonstrated this with the June sowing being initially inferior to the August sowing but after 2.7 years the June sowing had a higher establishment than the August sowing (Table 4).

The quality of seedlings planted was important in experiment 8 where seedlings purchased from a State Forest nursery at Forbes varied from tall weak plants to shorter vigorous plants and this helped explain, respectively, the low establishment of *E. viminalis* and *A. melanoxylon* and the high establishment of *E. blakelyii* and *E. albens* (Table 11) after sowing in July 1997. The low establishment of *P. radiata* in the same experiment (31%) was due to two-year old seedlings being supplied by State Forests at Tumut. One year-old vigorous seedlings of *P. radiata* planted in the same year 1997 from the Tumut source had a much higher establishment (87%) in experiment 6 (Table 9) despite being sown later, ie in September.

Control of Competition

Although trees established in experiment 1 in unsprayed serrated tussock, a similar result was never achieved again. The density of trees that established in unsprayed tussock in experiment 1 declined substantially over time due to the competition from weeds in dry summer/autumns (Table 2).

Aerial Sowing and Direct Drilling: In all but experiment 1 weed control was the major factor on which success depended. This result agrees with many, eg, Bird *et al.* (1990). The weeds that caused the most problems were not serrated tussock or St. John's wort but annuals that established with the trees and grew during the first spring. Efforts to control these annuals included spray-topping in the spring before sowing, spraying immediately before sowing and pre- and post-emergence herbicides. Spray-topping where annual grasses, eg, *Vulpia* spp. are present is essential as is spraying prior to sowing. Initially Roundup CT® was applied at 1.5 to 2 Lha^{-1} immediately before sowing in experiment 2 but due to poor control of *Vulpia* spp. the rate was increased, until in experiment 10, 4 Lha^{-1} was applied and this rate still did not give the required degree of weed control for establishment from aerially sown seeds.

Pre-emergence herbicides, in addition to Roundup CT®, were applied in experiments 6 and 8 without substantial assistance to establishment of aerial or direct drilled seedlings. These herbicides do not control the weeds for long enough after sowing into the first spring to assist establishment. It is possible that pre-emergence herbicides could be more effective if applied in mid winter to kill the first germinations of annual weeds and a knockdown herbicide applied 2 months later immediately before sowing.
This would allow the pre-emergence herbicide to kill successive germinations of annuals and deplete the bank of weed seed in the soil.

For aerially sown eucalypts to establish it is necessary to have almost complete weed control during the spring after sowing. This was achieved in experiment 7 because the area had been burnt three years before sowing and sprayed in the following two years and good establishment of aerially sown seed resulted (Table 10). Another way of controlling weeds in the spring after sowing is to apply post-emergence herbicides. This was done in experiments 8 and 10 but the herbicides did not assist establishment. The herbicides did reduce weed competition substantially but they also had deleterious effects on the tree seedling. Glasshouse experiments have shown that although the post-emergence herbicide will kill weeds, tree seedlings (6 weeks old) were sensitive to low rates (Campbell and Nicol 1998). Therefore, for the post-emergence herbicides to be effective they must be applied at an accurate rate and there is not a great deal of tolerance by the young tree seedlings of excess rates. A new study (Moore 1999) has revealed other post-emergence herbicides than used in this project that could selectively remove weeds from establishing trees which need testing in the field in the follow-on to this project.

If tree seedlings survive competition in spring from annuals the next hurdle is to survive competition from perennials (St. John's wort, skeleton weed, redleg grass, great mullein) in summer. As selective post-emergence herbicides have little effect on these weeds the trees have to be able to survive this competition through their own competitive ability and that is where species that grow quickly (e.g. *E. viminalis, E. camaldulensis)* are better adapted than others.

Fertilizer (superphosphate) was applied in experiment 1 and had a deleterious effect on establishment of aerially sown and direct drilled seedlings by promoting native legumes. Establishment from aerial seeding and direct drilling was more difficult on sites with higher fertility than on sites with low fertility in these experiments because weed control on the high fertility sites was not sufficiently effective to allow establishment.

Planted Seedlings: In all experiments weed control with herbicides was attempted only in the year of establishment; after that trees had to survive without assistance.
Planted seedlings were able to compete with weeds far better than aerial sown or direct drilled seedlings. Herbicide treatment prior to sowing was essential in all experiments for maximum long-term (2 to 4 years) survival (eg Table 3). However growth and survival of trees could be substantially improved by applying selective herbicide in at least the year following sowing.

Seedbed Preparation

Aerial Sowing and Direct Drilling: In experiment 1 eucalypts established best where serrated tussock had been burnt and *P. radiata* established best where tussock had not been burnt (Table 1). This result reflects the size of the seed; eucalypts being small and their radicle being unable to grow through even small amounts of litter on the soil surface. *P. radiata* has a large seed and large radicle which needs protection while trying to enter the soil surface and this is supplied by dead plant litter. As serrated tussock leaves often fall onto the soil surface and form a horizontal mat after spraying, it is difficult for the radicle of eucalypts to enter the soil. This form of litter does not favour *P. radiata* radicles either; litter that remained vertical assisted *P. radiata* in experiment 6 and thus the arrangement of the litter has to be favourable for optimum establishment.

Planted Seedlings: A seedbed with dead tussock leaves lying horizontal on the soil surface is ideal for the establishment of planted seedlings because the dead leaves control weeds, conserve soil moisture and the residual Frenock® leaching from the leaves kills tussock seedlings trying to establish.

Species

Aerial Sowing and Direct Drilling: Of the many species sown in the experiments *P. radiata* was outstanding. It established well from direct drilling in most experiments and was one of the best from aerial seeding; it was relatively more successful than other species in the difficult climate of the Monaro (Tables 6 and 7). In experiment 3 the percentage establishment of viable seed of *P. radiata* from direct drilling was 60% compared to that of *E. viminalis, E. macarthurii and E. aggregata* of, respectively, 8.6%, 6.4% and 0.1%. In experiment 9 percentage establishment of viable seed from direct drilling was: 71%, 3.7%, 1.5% and 1.3% for, respectively, *P. radiata*, *E. viminalis, E. polyanthemos* and *E. melliodora*. Establishment from aerial seeding was much lower, ie, for the species in experiment 3, 25%, 2.0%, 1.6% and 0.2% and for the species in experiment 9, 18%, 1.6%, 1.1% and 0.5% respectively. The establishment in these experiments was generally higher than in other experiments but because seeds of the eucalypts are so small a 1% establishment is quite acceptable giving 13 and 33 trees $10m^{-2}$ for *E. viminalis* and *E. melliodora* respectively at sowing rates used in these experiments. For *P. radiata* a 5% establishment of viable seed would be acceptable because it would give 10 trees $10m^{-2}$ from a sowing rates of 8 kg ha^{-1}.

Another advantage of *P. radiata* over the eucalypts is that it is tolerant to pre- and post-emergence herbicides whereas eucalypts are quite sensitive. However a seedbed of dead plant litter is needed for establishment of aerial sown *P. radiata* and inoculation with mycorrhiza is needed for aerial sown and direct drilled seed.

P. radiata also has an advantage over eucalypts and wattles in that it has dense foliage which cuts out almost all light to weeds. Eucalypts have a less dense foliage which cuts out less light than the *P. radiata* and thus a greater density of eucalypts is required to control weeds.

Of the eucalypts the most promising species to establish from aerial sowing and direct drilling were: *E. viminalis, E. melliodora, E. camaldulensis* and *E. polyanthemos*. However long-term establishment will depend on species that can survive in different hill country environments. Therefore it may be better to sow some species, eg, *E. blakelyii* and *E. albens,* that have been proven to survive on hill country in the Tuena district despite their lower initial establishment. This can only be proven by continuing the experiments over the long term.

The wattle species sown failed to establish from aerial sowing but established well from direct drilling. *Acacia melanoxylon* established well from direct drilling in the latter experiments and was sown in these experiments in preference to *A. dealbata* which, despite establishing in experiments 1 and 2, was attacked by diseases and insects that limited it's survival.

Planted Seedlings P. radiata was also outstanding in establishment when planted as seedlings because of it's ease of establishment in the different environments and different years and because of it's high survival rate over the experimental periods. On the Monaro, 2.3 years after sowing, it was the only species to establish and survive in experiment 4 and had the highest establishment of all species in experiment 3 (66% meaned for the June and September sowings). Of the five experiments at Tuena where *P. radiata* seedlings were sown in competition with other species, it had the highest establishment in three; in the other two experiments two-year old low-quality seedlings were sown.

Root Additions

The mycorrhiza necessary for the establishment and survival of *P. radiata* could be supplied by inoculating seed of this species before sowing which would be preferable to supplying large amounts of litter from under established trees but this aspect of establishment need further research to solve this problem. A similar position exists for the introduction of *Frankia* onto the roots of *C. cunninghamiana.*

Insects and Other Pests

Treatment of seed to reduce losses due to ants (Campbell and Gilmour 1979) was quite successful. In experiment 1 seeds of *P. radiata* were taken by birds or mice. Wire cages placed over half the treatments in experiment 6 showed that birds did not take seeds in that experiment. However the large seeds of *P. radiata* and *B. populneum* were taken by bird in experiment 8; in the direct drilled treatments the birds dug up seeds from under the soil surface. Loss of large seeds due to birds did not occur in other experiments.

Control of Serrated Tussock

The recommended density of *P. radiata* for control of serrated tussock of one tree $10m^{-2}$ (Hans Porada, State Forests of NSW, personal communication) was realized in many of the treatments in the above experiments and with attention to the findings of this project could be attained reliably from direct drilling and planting seedlings and less reliably from aerial sowing.
A greater density of eucalypts than one $10m^{-2}$ is necessary to control the weed. However, if animals are excluded from the area sown to eucalypts and burning is not practiced volunteer plants will control the serrated tussock in many situations. This occurred in all unburnt experiments (2, 4, 8, 10) in this project where some residual fertility was available for the volunteer plants to grow and multiply. Volunteers could be fostered by applying fertilizer once the trees had attained sufficient height to withstand competition for light.

Cost of establishing trees

The cost of establishing a *P. radiata* forest by planting seedlings (3x3 m intervals; 1100 trees ha^{-1}) as determined by State Forests of NSW (Andrew Croft, personal communication) is between \$1500 and \$2200 ha^{-1}.

The cost of establishing a forest by aerial techniques is as follows:

Table 17. Cost of establishing trees by aerial techniques

Time of treatment	Treatment ha^{-1}	Cost ($ ha^{-1})
October, year 1	Aerial spray to kill serrated tussock, native grasses and annuals. Glyphostae 4 L, $24; and aerial application, $35.	59
Year 2	Graze hard to stop weeds seeding, spray-top in October. Glyphosate 0.5 L, $3; aerial application, $20	23
Year 3	Graze hard, spray in mid to late winter to kill annual weeds. Glyphosate 3 L, $18; aerial application $35	53
	Electric fence $70; rabbit control $30	100
	Aerial sow seed: Routine *P. radiata* at 8 kg @ $150 kg; aerial sowing and seed treatment $15	1215
	Aerial sow seed: GF 19 *P. radiata* at 8 kg @ $400 kg; aerial sowing and seed treatment $15	3215
	Aerial sow seed: eucalypt at 4 kg @ $160 kg; aerial sowing and seed treatment	654
	Aerial sow seed: wattle at 4 kg @ $75 kg; aerial sowing and seed treatment	314
Total cost	Routine *P. radiata*	1450
	GF 19 *P. radiata*	3450
	Eucalypt	889
	Wattle	549

The cost of establishing a forest by direct drilling would be slightly higher than the cost of aerial treatments.
Of the four options chosen in Table 17 three are less costly than planting seedlings. The immense cost of the seeds and the high seeding rates used in the aerial treatments allows for considerable cost savings to be made. There are problems in obtaining large amounts of tree seeds to sow large area at the one time. Sufficient notice has to given to seed merchants to allow sufficient time to obtain quantities of seed of the order of >100 kg.

Implications

The main problem in controlling serrated is the difficulty of control on non-arable land. Up till 1998 aerially applied Frenock® was used to kill serrated tussock on unploughed hill country. This was a non-sustainable control method as the weed returned within 3 to 10 years after spraying. The sustainable approach of sowing pastures after spraying was uneconomic (Vere *et al.* 1993) and thus not used on country with low rainfall and infertile soils. In late 1998 Frenock® was taken off the market and now we have no method for controlling the weed on hill country. Therefore the use of trees as a control needs to be investigated.

This project shows that trees can be established for the control of serrated tussock by aerial sowing, direct drilling and planting seedlings. The advantages of aerial sowing and direct drilling are that they are relatively cheap (see ***Cost of establishing trees***) and rapid. Results showed that aerial sowing can be successful in gaining initial establishment of trees but it is unreliable as a method of establishment at the present state of knowledge. Thus further research on the use of aerial sowing is needed. Direct drilling was a reliable method of establishment and could be used where it is possible to use sowing machinery but will be limited by steep slopes. Planting seedlings was the most reliable method of establishment but is limited by cost and rate of planting (16 hours to plant 1 ha of *P. radiata;* personal communication, Andrew Croft, State Forests of NSW).

For each method of sowing it was necessary to kill serrated tussock with herbicides. In early 1998 this could be done by aerial application of Frenock® but as Frenock® is no longer available the only alternative, Roundup®, applied at a rate that will kill serrated tussock will also kill or seriously damage existing trees. Thus if these trees are of value the only way to kill the tussock is to aerially apply Roundup® without contacting the existing trees which in most areas will be difficult.

The best tree species for the control of serrated tussock, *P. radiata*, needs a seedbed of dead plant tissue for establishment from aerial sowing. This can be provided by managing the pasture, ie, either spelling or grazing, before or after spraying. In situations with a heavy tussock infestation it may be necessary to wait for one or two years after spraying for the tussock litter to break down and provide a favourable seedbed. For eucalypts the seedbed needs to have a large proportion of bare soil which can be provided by burning in late winter or early spring and combined with grazing management can produce a seedbed with small amounts of litter and predominantly bare soil. The wattles sown in this project failed to establish successfully from aerial sowing.

Most tree species established well from direct drilling. The major requirement was a wide (15 cm to 20 cm) drill run which removed most weeds and weed seeds from near the establishing tree seedlings.

Planted seedlings established well provided that the seedlings were vigorous and of high quality at planting.

Therefore by implementing the findings of this project it will be possible to establish trees to replace weeds on hill country. The costs of establishing trees to control weeds will be lower from aerial seeding and direct drilling than from planting seedlings. However the risk of failure will be lower from the latter method. Landholders may be able to afford to establish trees on small areas of their properties but large scale plantings will be beyond the capabilities of normal producers. In favourable areas trees could be grown as a profitable crop with the landholder tending the trees and either selling them as timber or milling them on the property.

However, much of the hill country infested with weeds is potentially low producing and thus weed control with trees will be instigated with the object of ceasing agricultural production, ie, returning the country to tree dominance. This will restrict the spread of weeds such as serrated tussock but can only be funded by public intervention in the weed control process. Jones *et al.* (1999) have economically assessed this situation and have concluded that on low rainfall-low soil fertility country, the socially optimal control option for serrated tussock is to retire the land from agricultural production and re-vegetate it with trees.

Recommendations

This project has shown that under certain conditions trees can be established by aerial sowing in sufficient density to control weeds. At present our knowledge of the conditions necessary for establishment are incomplete, therefore the most important recommendation from the project is to continue research to improve the reliability of establishment of trees by aerial sowing.

To disseminate the knowledge that we do have, large scale demonstrations should be set down in different regions of the state to demonstrate the effectiveness of various control techniques using trees.

Financial strategies need to be developed to enable landholders or Government to retire low-producing weed infested land from agricultural production by sowing trees.

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Structure of Final Report (a reminder & general guidelines)

REMEMBER: YOUR FINAL REPORT MUST BE SENT IN BOTH HARDCOPY AND ON DISK.

THE DISK COPY MUST CONTAIN THE COMPLETE REPORT, WITH ALL GRAPHICS AND TABLES EMBEDDED IN ONE DOCUMENT, IN Word FORMAT (disk can be IBM 3.5 floppy, 100mg ZIP disk, or a CD rom)

**Note: Ensure your report is 'camera ready':
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Typestyle and Layout

Page format:	A4 portrait: vertical not horizontal!
Page Setup:	Front Page: Top 1cm, Bottom 2.5cm, Left Margin 2.5cm, Right Margin 2.5 cm All others: Top 2.5cm, Bottom 2.5cm, Left Margin 2.5cm, Right Margin 2.5 cm
Page numbers:	for preliminary pages (from title page to just before introduction) to be in roman numerals, italics, and centred (eg. *iv*, *v*, *vi*, *ix*). Please omit number from title page and start at ii. For body of report (ie. from "Introduction" section onwards) to be in normal type (eg. 1, 2), and centred. All pages, including appendices, to have page numbers. Numbers on appendices to run-on continuously from body of report. All reports will be printed double-sided.
Headings:	(and sub-headings) to be in a bold sans serif type (eg. Arial) and left-hand aligned, not indented or centred. **Heading 1: Arial Bold 22 point** **Heading 2: Arial Bold 14 point** **Heading 3: Arial Bold 12 point** *Heading 4: Times New Roman Italic 11 point* Body Text/Normal: Times New Roman Regular 11 point
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Research Report Structure

Preliminary Pages:

i	Title page (right-hand side) – please hide page number
ii	Disclaimer page
iii	Foreword (right-hand side)
iv	Acknowledgments if any, or About the Author (or just leave blank)
v	Contents (right-hand side)
vi	List of Tables, Figures, Abbreviations (if necessary)
vii	Executive Summary (max 5 pages, focus on results)

Body of Report:

Introduction	Background to the project. starts as page 1.
Objectives	
Methodology	Including a description and justification.
Detailed Results	Including statistical analysis.
Discussion of Results	Compared with the objectives.
Implications	Assessment of the impact of the outcomes on industry in Australia (where possible provide a statement of costs and benefits).
Recommendations	On the activities or other steps that may be taken to further develop, disseminate or to exploit commercially the results of the Project.
Appendices	If necessary.
Glossary	Optional.
Bibliography/references	

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