COOPERATIVE RESEARCH CENTRE
FOR SUSTAINABLE PRODUCTION FORESTRY

Greening Australia

Technical Report 152
Herbicide Tolerance of Australian Native Plants in a Direct-Seeded Shelterbelt in the Midlands of Tasmania
C.T. Nardon, P.J. Smethurst, W.R. Gibson, J.C. Waugh

Non-confidential

Herbicide Tolerance of Australian Native Plants in a Direct-Seeded Shelterbelt in the Midlands of Tasmania

C.T. Nardon[1, 2], P.J. Smethurst[2, 3], W.R.. Gibson[4], J.C. Waugh[5]

CRC Project B3

CRC Deliverable 1.8 'Provide a prescription for site and
species selection, and establishment and management of
plantations to combat tree decline in Midlands of Tasmania'

[1]University of São Paulo, Piracicaba, Brazil
[2]Cooperative Research Centre for Sustainable Production Forestry
Private Bag 12, Hobart, Tasmania 7001
[3]CSIRO Forestry and Forest Products
[4] "Scone", PO Box 12, Perth, Tasmania 7300
[5]Greening Australia; currently Bega Valley Shire Council

June 2005

ABSTRACT

'Tree decline' is a national phenomenon in the agricultural landscape that affects several areas of Tasmania. An option for addressing this problem is revegetation with native plants in shelterbelts, which can be established using planted seedlings or direct-seeding. Weed control is essential for successful establishment.

The main objective of this study was to determine the tolerance of 22 species of direct-seeded native Australian plants to several herbicides applied either pre-sowing or several months after sowing as an over-spray. To minimise weed competition in all treatments, this ex-pasture site near Perth, Tasmania, was sprayed three times with Roundup prior to the experimental pre-sowing treatments.

One experiment included 10 pre-sowing and 3 overspray treatments in factorial combination. A second experiment had no pre-sowing treatments, but 10 overspray treatments. Stocking was assessed between the two spray times, one year later, and at age 11 years. Also at age 11 years, plant size was assessed.

Pre-sowing sprays of Gesatop and Gesaprim reduced stocking by 35% in 1995, and the effect was still evident in 2005. Other pre-sowing sprays did not significantly change stocking. Over-spraying of several herbicides increased stocking. The three dominant species were *Eucalyptus amygdalina, E. viminalis* and *Allocasuarina verticillata.* Whereas, the most frequent species was *Acacia dealbata*, even though it made up only 2% of the number of seeds in the mix. There were some indications of species-specific interactions to herbicides, but this was not a strong effect. Averaged across the site, overall high stocking (20,000 plants ha^{-1}) and total basal area (44.8 m^2 ha^{-1}) at 10 years of age were indicative of generally successful establishment, survival and growth. Total basal area and growth of dominants were less sensitive to treatment than stocking at age 11 years, possibly because very dense stocking would have affected growth in neighbouring plots by this age.

At this site, and generally for the species tested, good weed control led to successful shelterbelt establishment. The very high sowing rate and concomitant competition induced self-thinning that is likely to continue to develop and might eventually threaten the effectiveness of the shelterbelt.

In summary, our results did not demonstrate any major benefit of these herbicides on stocking or growth in this plantation, but they showed that most of the herbicides used were safe for use during establishment of several native species by direct-seeding in the Tasmanian Midlands, because they did not cause serious damage to these species. Exceptions were Gesatop and Gesaprim, which should not be used pre-sowing, but they could be used after establishment. At this site, initial weed control by Roundup may have left little opportunity to demonstrate the benefits of the herbicides. The potential use of the herbicides may lie in plantations where initial weed control is less effective.

INTRODUCTION

Tree Decline

'Tree decline' is a national phenomenon that refers to the progressive loss of vigour and ultimate death of individuals or stands of native trees (mainly eucalypt dominated) in the agricultural landscape (Photo 1). Symptoms begin with foliage loss (crown thinning) at the ends of branches, followed by total foliage loss and then death (Close 2002). During the past three decades, tree decline has reached unprecedented levels (Rees 2000). However, considerable patchiness occurs on a local scale and some species are more susceptible than others (Close 2002). All the forests of the low rainfall districts of Tasmania are affected by 'dieback' to some extent (Neyland, 1996).

Photo 1. Early (left) and late (right) stages of tree decline in the Midlands of Tasmania

A number of factors have been associated with tree decline, and, although poorly understood, the current view is that it is a response to a complex interaction of factors associated with climate and rural land use. These factors include ectomycorrhizal fungi, nutrient balance, water availability, competition with introduced pasture species, pest-predator balance, tree age and fire regime (Close and Davidson 2001, Close and Davidson 2002). The severity of decline in Tasmania also increases with the degree of native vegetation removal, degree of pasture improvement, and grazing intensity (Mackay 1978, Mackay et al. 1984, Nadolny 1984, cited by Close 2002).

Tree decline in the cold, dry Midlands of Tasmania is typified by the decline of isolated trees in pastures or of small patches of trees where all other native vegetation has been cleared. In some cases, decline in this region seems to be less severe on slopes of low soil quality where pastures are typically neither fertilised nor improved. Thus, tree decline in the Midlands is partially caused by the combination of competition for water between trees and improved pasture, other effects of high intensity grazing, and relatively low landscape positions subject to low temperatures (Close 2002).

To increase the coverage of trees in this landscape, commercial and non-commercial options have been suggested. Farm forestry for commercial wood production is an emerging industry that has been promoted as a viable and complementary economic enterprise alongside livestock and crop production. However, given the constraints of low temperature and low rainfall in the Midlands, farm forestry might not be an economically viable option. An alternative is revegetation with non-commercial trees managed for the purposes of biodiversity, soil and water conservation, and shelter that would also strengthen the economic viability of agriculture (Close 2002).

Shelterbelts

Farm animals can suffer from exposure to extremes of climatic conditions that limit their productivity. Hence, those provided with suitable shelter from the sun and wind are commonly more productive than those left exposed (Hall and Burns 1991). Shelterbelts of moderate permeability provide more suitable protection than a solid barrier such as a brick wall, because they produce less turbulence on the downwind side. A large-scale experiment at the University of New England research farm indicated that an increase of more than 20% pasture production occurred on paddocks sheltered by patchy, small shelterbelts. This was attributed to shelter from the wind and cold air flowing down slope (C. Naldony pers. comm., cited by Close 2002). Multiple-row shelter belts, such as used at the present site, are by nature like a narrow plantation, but their design is important. For example, when two or more tall-growing species are used in a multi-row belt, a particular constraint can be that only one species can be planted per row. Eucalypts should be planted in the centre or on the leeward edge, because they normally have a bare lower stem. Pines or other species that retain foliage to the ground should be used on the windward side. In the case of low-growing bushy shrubs, some mixture of species in an outer row is desirable for aesthetic purposes provided their rates of growth are similar (Hall and Burns 1991).

Shelter-belts can be established using planted seedlings or sown seeds (i.e. direct-seeding) of native or exotic species. Many workers in the revegetation ‘industry’ prefer native over exotic plantings due to aesthetic, conservation, biodiversity and pest-predator balance reasons. Those supporting exotic plantings suggest there is a greater likelihood of survival and growth compared to natives, with the resulting environmental benefits from reduced soil and wind erosion and reduced salinity. Direct seeding allows natural selection of individuals through competition and is more cost effective than planting seedlings, but it carries greater risk of failed establishment and can result in dense thickets of acacias only (Close and Davidson 2001, Close and Davidson 2002). A high incidence of failed establishment or poorly performing shelterbelts has led to a recommendation to test new approaches (Close 2002). Suggested new approaches include the consideration of soil type and aspect, the use of fire for producing ash-beds, inoculation of ectomycorrhizal fungi, direct seeding techniques, seedling nursery management, minimising competition from weeds, and the effects of nitrogen-fixing companion plants. Weed management was considered critical (Close and Davidson 2001, Close and Davidson 2002). It has been argued also that direct seeding is more ecologically sound as it allows the natural selection of genetically superior individuals and that the higher plant density appears to lead to more effective suppression of grass competition (Parker 1994). Seedlings established from seed are also considered more robust and resistant to stress (Neyland 1996) and it is a significantly more cost-effective method (Parsons 1999). However, direct-seeding is also extremely risky in low rainfall regions (Pinkard 1992).

Weed Control

Weed competition with planted tree seedlings is a problem in revegetation projects because it reduces the availability of nutrients, water and light for tree growth (Marchi et al. 1995). The economic benefit of weed control in commercial plantations was established many years ago, and today is a standard practice especially on ex-pasture sites (Hall and Burns 1991).

Weed control practices for direct-seeded shelter-belts are not well defined and can have quite different goals to those in commercial plantations. For example, in commercial plantations of introduced species, suppression of native plants is a major goal, but the opposite can be true when establishing natives on land dominated by introduced pasture species. Effective techniques based on herbicides are available for weed control in plantations of the commercial forestry species. However, because of differences in species tolerance, these techniques are not always applicable to growing the diverse range of native Australian species that are being planted for amenity and conservation purposes (Campbell and Nicol 1998, Hall and Burns 1991). Hence, there is a pressing need to refine weed control options for the latter situation. Control of pasture species might need to be continued until the young trees and shrubs have grown to a stage where such competition will not affect their growth (Close and Davidson 2001, Close and Davidson 2002). Although, the effect of weed competition has rarely been reported for direct-seeded shelter-belts, it appears that the triazine groups of herbicides, which are widely used for conifer establishment, should not be used on some *Acacia* species (Hall 1986).

In some areas subjected to agricultural practices for many decades, a significant seed-bank exists in the soil that is able to re-colonise after an initial knockdown herbicide application. Also under these conditions annual grasses and broadleaf weeds pose a problem, competing with the planted trees for resources necessary for their successful establishment (Churchill 2004).

The objectives of research reported here were to (1) determine the tolerance of some direct-seeded native Australian plants to several herbicides applied pre- and post-seeding, (2) demonstrate that direct-seeded native shelter-belts can be successfully established in the Midlands of Tasmania if good weed control practices are employed, (3) suggest best-bet options for establishing shelter-belts under these conditions, and (4) identify priorities for future research in relation to establishing these shelter-belts.

METHODS

Site

The site was on the “Scone” property c. 2 km south of Perth, Tasmania (grid reference 147947, Longford 1:25,000 map), and on the boundary between the ‘Cow’, ‘Sorrel’ and ‘Cyclone’ paddocks (Appendix 1). Annual rainfall during the period of the experiment (1995-2004) varied widely and averaged 579 mm, which is 15% less than the long-term average of 683 mm over 73 years of records, but only 1% less than the average for the past 17 years (583 mm, 1987-2004). Long-term average temperature at the site is 11.5°C (Figs. 1 and 2).

The site had a slope of less than 5° and a south-west aspect along a broad drainage line. The soil was shallow, texture-contrast, poorly-drained and on the boundary of Newham and Brickendon Associations (Spanswick and Zund 1999). It consisted of a brown loam A_1 horizon (c. 0-25 cm), a bleached or non-bleached A_2 (c. 25-40 cm) with iron-stone and quartz gravel (2-25 mm diameter) common in the lower half of the horizon, over brown medium clay with grey mottles. Chemical analyses of surface soil (0-10 cm) averaged from neighbouring paddocks are shown in Table 1. These data suggest pH and nutrient levels at the site were suitable for the growth of most native plants, even though the experimental site might have been of lower fertility because it received a lower rate of fertilization than that used in adjacent pastures.

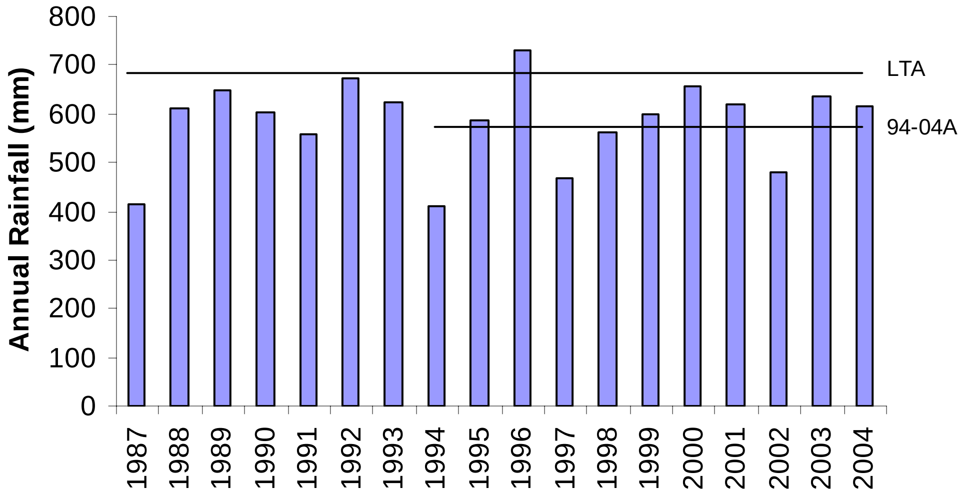


Fig 1. Annual rainfall at 'Scone' from 1987 to 2004 compared with the 73-year long-term average (LTA) and that during the experiment (94-04A).

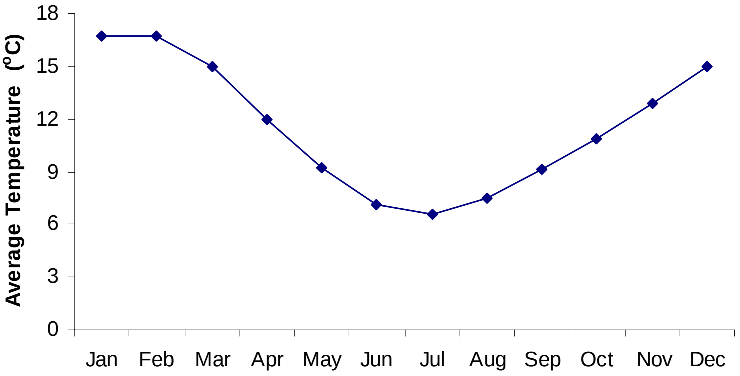


Fig 2. Average monthly temperature at 'Scone' in 2004.

Table 1. Averages of some soil chemical analyses of the "Cow Paddock", "Cyclone Paddock" and "Sorrel Paddock" adjacent to the site.

pH	**5.3**
Organic C (mg g^{-1})	**21.3**
$P_{Colwell}$ (μg g^{-1})	**31.3**
P_{Olsen} (μg g^{-1})	**16.5**
Sulphate Sulphur (μg g^{-1})	**8.9**
Cation Exchange Capacity ($cmol_+$ kg^{-1})	**3.28**
Exchangeable Ca (μg g^{-1})	**370.6**
Exchangeable Mg (μg g^{-1})	**80**
Exchangeable K (μg g^{-1})	**169**
Ca/Mg	**4.7**
Exchangeable Sodium Percentage (%)	**4.25**
B (μg g^{-1})	**0.33**

Native vegetation in the area prior to clearance was open woodland dominated by *Eucalyptus amigdalina* and *E. viminalis*, but, immediately prior to direct seeding it was pasture dominated by perennial rye grass (*Lolium perenne*), cocksfoot (*Dactylis glomerata*), subterraneum clover (*Trifolium subterraneum*) and white clover (*Trifolium repens*).

During the 1.5 years prior to direct seeding, 3 applications of glyphosate were applied over the entire experimental area to kill the existing pasture on (1) 15th April 1993, 5 L ha^{-1} Glyphosate 360®, (2) 6th September 1993, 5 L ha^{-1} Glyphosate 360® plus 50 mL ha^{-1} LeMat® and 2 mL L^{-1} Wetter TX®, and (3) 15 weeks before the experiment 3L ha^{-1} Glyphosate 360® and 2 mL L^{-1} Wetter Tx®. These spray applications were not part of the experimental design.

Direct-Seeding

Species used in both experiments are listed in Table 2 along with some of their characteristics. Seeds were sown using an 'Ecoseeder' that removed ('scalped') a strip of soil and placed it overturned and adjacent to the scalped zone, then incorporated the seed in the exposed soil of this zone (Photo 2).

Table 2. Species used in the direct seeding experiment at 'Scone'.

Code	Species	Habit and Native Distribution	Weight of Seed in Mix (g)	Seed Weight[1] (seeds g^{-1})	Proportion of Mix by Seed Numbers[2]
Ad	*Acacia dealbata*	Shrub or medium-sized tree (6-15 m); Vic. and Tas.	500	110	1.7%
Ame	*Acacia melanoxylon*	Tall Tree (10-20 m); NW Tas., Vic.	250	60	0.8%
Amu	*Acacia mucronata*	Small tree (2-8m); Tasmania and Victoria.	150	110	0.9%
Ap	*Acacia pravissima*	Small tree (3-8 m); NE Victoria to NSW Tablelands.	250	200	2.6%
All	*Allocasuarina littoralis*	Small tree (6-12 m); NSW, NSW and Queensland.	300	500	7.9%
ALm	*Allocasuarina monilifera*	Small tree (6-12 m); Tasmania and Victoria.	150	500	3.9%
Alv	*Allocasuarina verticillata*	Small much-branched tree (4-7 m); Tasmania.	500	400	10.5%
Bm	*Banksia marginata*	Sturdy-trunked tree (7 m); Tasmania.	100	180	0.9%
Bs	*Bursaria spinosa*	Erect shrub or tree (3-8 m) Victoria.	300	500	7.9%
Cp	*Callistemon pallidus*	Erect shrub (2-4 m); Tasmania and Victoria.	300	25000	-
Cv	*Callistemon viridiflorus*	Erect shrub (1-2 m); Tasmania.	50	25000	-
Co	*Callitris oblonga*	Shrub or small tree (2.5 m) Tasmania.	100	118	0.6%
Cr	*Callitris rhomboidea*	Shrub or small tree (2.5 m) Tasmania.	100	240	1.3%
Ea	*Eucalyptus amygdalina*	Medium-sized to tall Tree (15-30 m); Tasmania.	500	150	3.9%
Ej	*Eucalyptus johnstonii*	Tall tree (up to 40 m) Tasmania	150	90	0.7%
Eo	*Eucalyptus ovata*	Tall tree (15-30 m); Southeastern Australia	400	280	6.0%
Et	*Eucalyptus pauciflora*	Medium-sized tree (10-20 m); New South Wales, Victoria and Tasmania.	800	60	2.5%
Er	*Euclyptus rodwayii*	Small tree (9-18 m); Tasmania	200	65	0.7%
Et	*Eucalyptus tenuiramis*	Small to médium-sized tree (8-25 m); Tasmania.	450	100	2.4%
Ev	*Eucalytpus viminalis*	Tall tree (30-50 m); Tasmania and Victoria.	300	170	2.7%
Ll	*Leptospermum lanigerum*	Erect much-branched shrub 3-4 m; Victoria and New South Wales.	250	1000	15.8%
Ls	*Leptospermum scoparium*	Shrubs (2-4 m); Tasmania, Victoria, New South Wales, Queensland.	350	1000	26.3%

[1] Data obtained from several websites. [2] Excluding Cp and Cv.

Experimental Design

There were two experiments. Experiment 1 combined 10 pre-sowing with 3 over-spray treatments. Experiment 2 included 10 over-spray treatments, but no pre-sowing treatments. Both experiments were arranged in a randomized complete block design with 3 replicates. Plots were each 10 m of a single row of direct seeding, and rows were 2 m apart. The spray area per plot was 10 m long and 1.2 m wide (Appendix 2) (Photo 2). The calendar of events was:

7th September 1994	Experiment 1 pre-sowing sprays applied during good conditions of humidity, temperature and gentle breeze; soil dry on the top
20th September 1994	seeding
1st – 23rd February 1995	first assessment
6th June – 26th July 1995	experimental over-sprays applied in both experiments, but interrupted by showers; cold temperatures
3rd – 4th April 1996	second assessment
18th – 24th March 2005,	third assessment

No additional weed control was applied. No fertilizers were applied.

Photo 2. The plot in the foreground shows the spray width and approximate length of one plot similar to that used in Experiments 1 and 2. Note the scalped furrow left by the direct seeder.

Treatment sprays were applied to plots 13 days before sowing or as over-sprays, 9-10 months after sowing, by which time many seedlings and some pasture weeds had emerged and were well-established.

Ten herbicides were used in Experiment 1, i.e. Roundup CT®, Goal CT®, Glean®, Flowable Gesatop 500®, Flowable Gesaprim 500®, Gesagard 500®, Kerb 50-WP®, Ally®, Surflan 500®, or a pre-sowing control (no herbicide). These were combined factorially with over-sprays of either Roundup CT®, Goal CT® or an over-spray control (no herbicide). The combination of no experimental herbicide at both pre-sowing and over-spraying is hereafter referred to as the Control treatment. Characteristics of the herbicides used are provided in Table 3.

In Experiment 2, herbicides tested as over-sprays were Roundup CT®, Goal CT®, Glean®, Flowable Gesatop 500®, Flowable Gesaprim 500®, Kerb 50-WP®, Surflan 500®, Agaprop®, Asulox® and Control (no herbicide).

Measurements

In 1995 and 1996, the central 5 m of each plot was assessed for the number of well-established plants, i.e. seedlings greater than 7.5 cm in height.

In 2005, the central 8 m of each plot was assessed for (1) the number of each tree species, (2) at least the central 3-8 m of each plot (minimum of 20 plants if available) for stem diameter over bark at 15 cm height, and (3) the diameter at breast hight (DBH) over bark and height of the three largest diameter trees and their species.

Stocking measurements and basal areas were calculated on a per metre basis of sown row. Basal area (cm^2 m^{-1}) was thus calculated as: $BA = \pi * DBH^2/(4*x)$, where BA= basal area (cm^2), DBH = diameter breast height (cm), and x = distance assessed (m). Where required, values of BA were divided by 2 to convert to units of m^2 ha^{-1}.

Statistical Analysis

Data were analysed by analyses of variance or covariance (Experiment 2 only) as provided in the Statgraphs® software, with $P = 0.05$ as a critical probability level unless otherwise indicated. Treatments means were compared using a least significant difference (LSD). The EXCEL® software was used to prepare the graphs shown in this report.

Table 3. Characteristics of the herbicides.

Code	**Herbicide**	**Active Ingredient (g kg^{-1} or g L^{-1} in product)**	**Type**[1]	**Weeds affected and other comments**	**Label Rate**[2] **(L ha^{-1})**	**Rate Applied**[2] **(L ha^{-1})**
R	Roundup CT	Glyphosate (410)	K Systemic	Annual grasses, perennial weeds, woody bush and trees	2-4	Pre-sowing 3 (E1) Over-spray 0.5 (E1) 1 (E2)
GO	Goal	Oxyfluorfen (250)	R and (K) Systemic	Annual grass and broadleaf; knockdown only during 2-3 weeks after emergence	4-6	Pre-sowing 6 (E1) Over-spray 3 (E1) 6 (E2)
GL	Glean	Chlorsulfuron (750)	R and K Systemic	Broadleaf weeds and some annual grass	53 g ha^{-1}	30 g ha^{-1}
GT	Flowable Gesatop 500	Simazine (500)	R Systemic	Annual grass and broadleaf weeds	2-4	6
GP	Flowable Gesaprim 500	Atrazine (500)	R and K Systemic	Grass and broadleaf weeds. Perennial species are not satisfactorily controlled	5-13	6
A	Ally (BrushOff)	Metsulfuron methyl (600)	(R) and K Systemic	Broadleaf weeds	5-7 g ha^{-1}	10 g ha^{-1}
AG	Agaprop	Propazine	K and R Systemic	Broadleaf weeds and annual grass		4
AS	Asulox	Asulan sodium salt (362)	K Systemic	Broadleaf and annual grass	4	12
K	Kerb 50 WP	Propyzamide (500)	R and K Systemic	Activity on annual winter grass; very high spray volume required (350-550 L ha^{-1})	8-14 kg ha^{-1}	6 kg ha^{-1}
G	Gesagard 500	Prometryn (480)	R and K Contact	Broadleaf and annual *Poa* grass	2-5	6
S	Surflan 500	Oryzalin (400)	R	Annual grasses and broadleaf weeds; relatively expensive	4.5-6.8	6
C	Control	-	NO HERBICIDE	-	-	0

[1] K – Knockdown, (K) – Weak Knockdown, R – Residual, (R) – Weak Residual

[2] Solid products indicated as g ha^{-1}. E1 = experiment 1, E2 = experiment 2.

RESULTS

Weed Growth

The three applications of glyphosate over the entire site prior to the experiment killed existing grasses and broadleaf weeds. Patches of Yorkshire fog grass (*Holcus lanatus* L.), cocksfoot (*Dactylis glomerata*), wild turnip (*Brassica rapa*), winter grass (*Poa annua*), hair grass (*Vulpia sp*) and barley grass (*Hordeum marinum*) regrew to various degrees during the experiment (Photos 3 and 4). This may have affected tree survival and growth, but weed coverage was not assessed in detail.

Photo 3. Weed competiton in 1996, 7 months after seeding. Note the reestablishment of pasture species between and within the rows of direct-seeded native plants.

Photo 4. Close-up of weed competition in 1996, 7 months after seeding. Note the reestablishment of pasture species between and within the rows of direct-seeded native plants.

In 1996, most of the plants were more than 7.5 cm in height and 4 mm in stem diameter. Some *Acacia dealbata* were 45-90 cm tall and 6-20 mm in stem diameter, some *Callistemon pallidus* 10-30 cm tall and 4-10 mm diameter, and some *Eucalyptus viminalis* 30-60 cm tall and 6-20 mm diameter.

Experiment 1: Combinations of Presowing and Overspray Treatments

General Observations

Several sown species were absent or only sparsely present in 1995 or 1996, i.e. *Allocasuarina littoralis* (ALl), *A. monilifera* (ALm), *Banksia marginata* (Bm), *Bursaria spinosa* (Bs), *Callistemon viridiflorus* (CAv), *Callitris oblonga* (Co), *C. rhomboidea* (Cr), *Eucalyptus johnstonii* (Ej), *E. rodwayii* (Er) and *Leptospermum lanigerum* (Ll), *L. scoparium* (Ls). (Fig. 3). Survival rates seemed to be unrelated to the rate of seeds sown per metre. By 2005, only nine species were present in the control treatment, i.e. *Acacia dealbata* (Ad), *A. mucronata* (Amu), *A. pravissima* (Ap), *Allocasuarina verticillata* (ALv), *Callistemon pallidus* (CAp), *Eucalyptus amygdalina* (Ea), *E. ovata* (Eo), *E. tenuiramis* (Et) *and E. viminalis* (Ev). Most common were *Acacia dealbata* (Ad), *A. pravissima* (Ap), *Allocasuarina verticillata* (ALv), each with a stocking of c. 1 plant m^{-1}. This survival rate compares to 35-150 seeds m^{-1} sown of these species. Height of the dominant trees in 2005 was c. 10 m. (Photos 5 and 6). A very small proportion of trees present in 2005 were dead. They were mostly *Eucalyptus* species (Fig 4).

Photo 5. A view of the narrow side (width 20 m) of the site in 2005. Average height of the dominant trees was 10 m.

Photo 6. A view of the long side of the site in 2005. Stocking was 20,000 plants ha^{-1}.

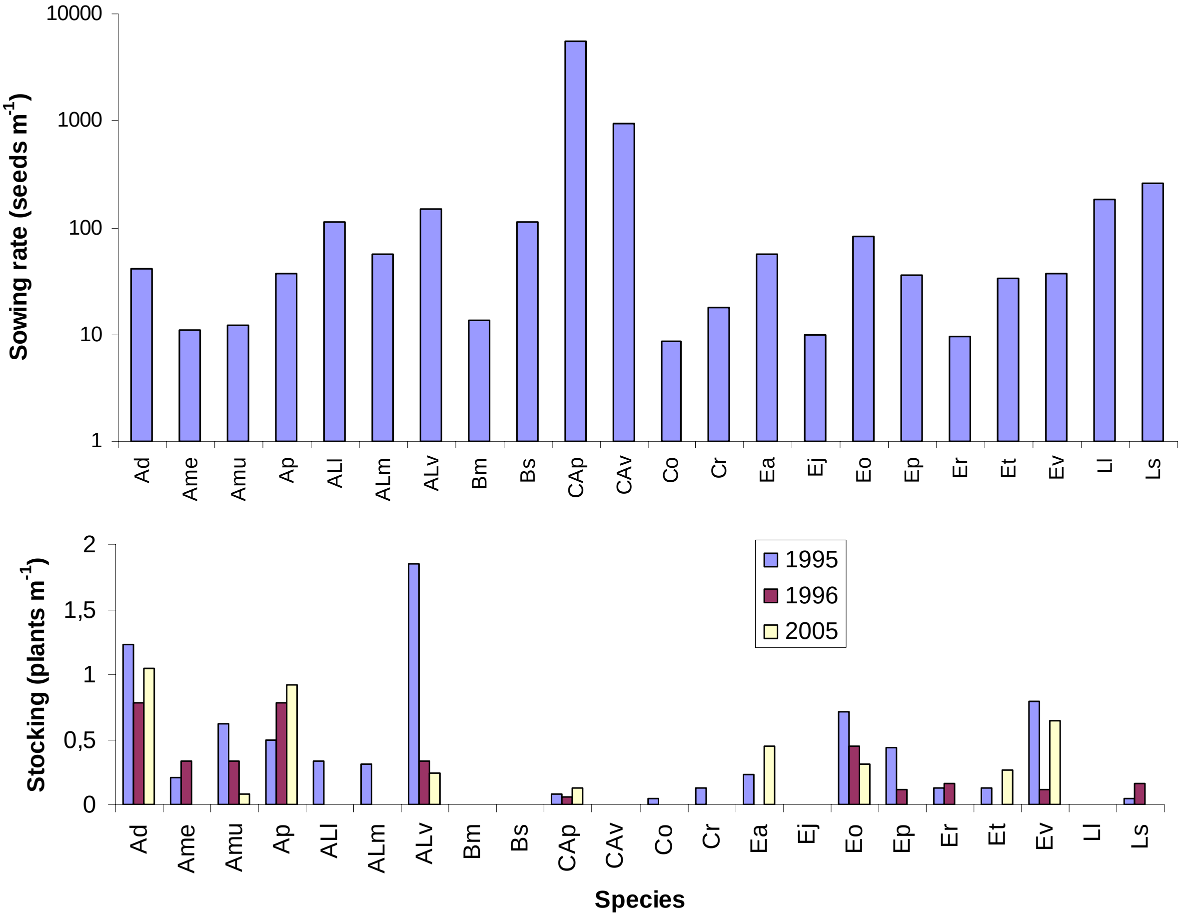


Fig. 3. Sowing rate of species direct-seeded in 1994 (top) and the resultant stocking in 1995, 1996 and 2005 (bottom) in the control treatment. Assessments in 1995 and 1996 were of well-established plants only. All plants were included in the 2005 assessment. Note the abundance of acacias, eucalypts and allocasuarinas in 2005 and that some species did not survive at all.

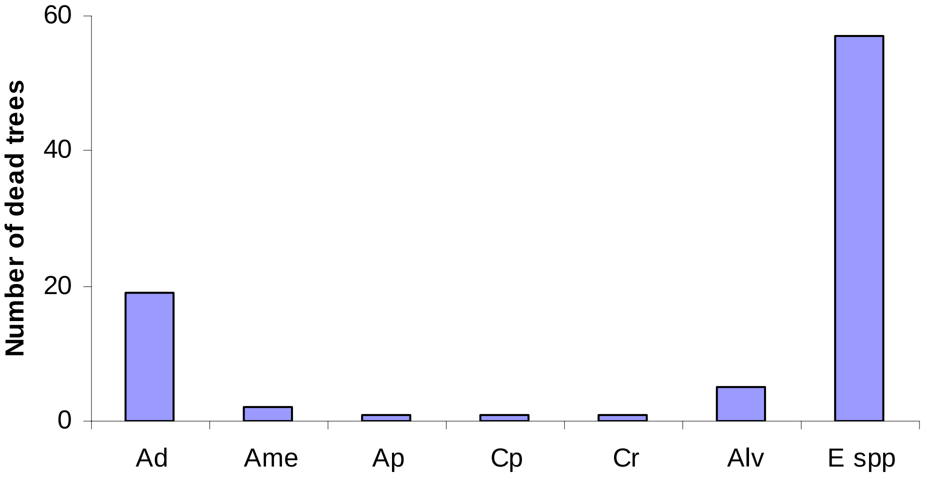


Fig 4. Dead species in 2005 for the total site. Eucalypts (E spp) could not be individually identified.

In the control treatment, i.e. no presowing or overspraying herbicide, stocking decreased from 7.7 well-established plants m^{-1} in 1995 to 4.0 in 2005 (Fig 5). This latter value is equivalent to 20,000 plants ha^{-1}.

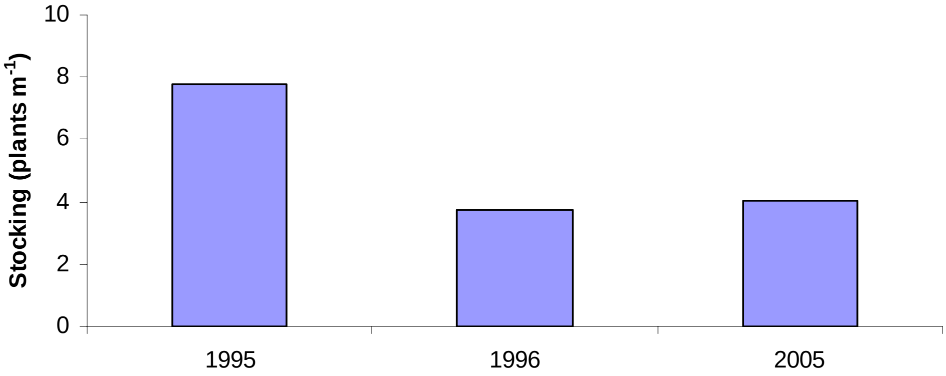


Fig 5. Stocking changes in the control treatment of Experiment 1.

Stocking

Both triazine herbicides reduced stocking significantly ($P<0.05$) if applied before sowing. At assessment in 1995, 5 months after sowing, GT had reduced the average stocking of well-established plants (combined over all species) to 3.5 plants m^{-1} compared with 7.8 plants m^{-1} in controls. GP reduced it to 2.7 plants m^{-1} (Fig. 6). This reduction was still evident in 1996 and 2005, by which time stocking was down to 1.6 plants m^{-1} (Fig 6). No other herbicide applied presowing had any clear effect on stocking (Fig. 6).

Main effects of presowing or overspray treatments were also evident for several dominant species individually (Table 4). For example, there was a significant presowing effect in *Acacia dealbata* (Ad) (Fig. 7). The overspray effect was significant for *Acacia dealbata* (Ad) (Fig. 8) and some other species in 1996, whereas, interactions with presowing were significant only for *Acacia pravissima* (Ap) in 1996. In this case, results suggested that the effect of overspraying depended on the presowing treatment that preceded it (Fig. 9). This interaction was strongest for a presowing application of GL, for which stocking was highest when followed by an overspray of GO and least when followed by R.

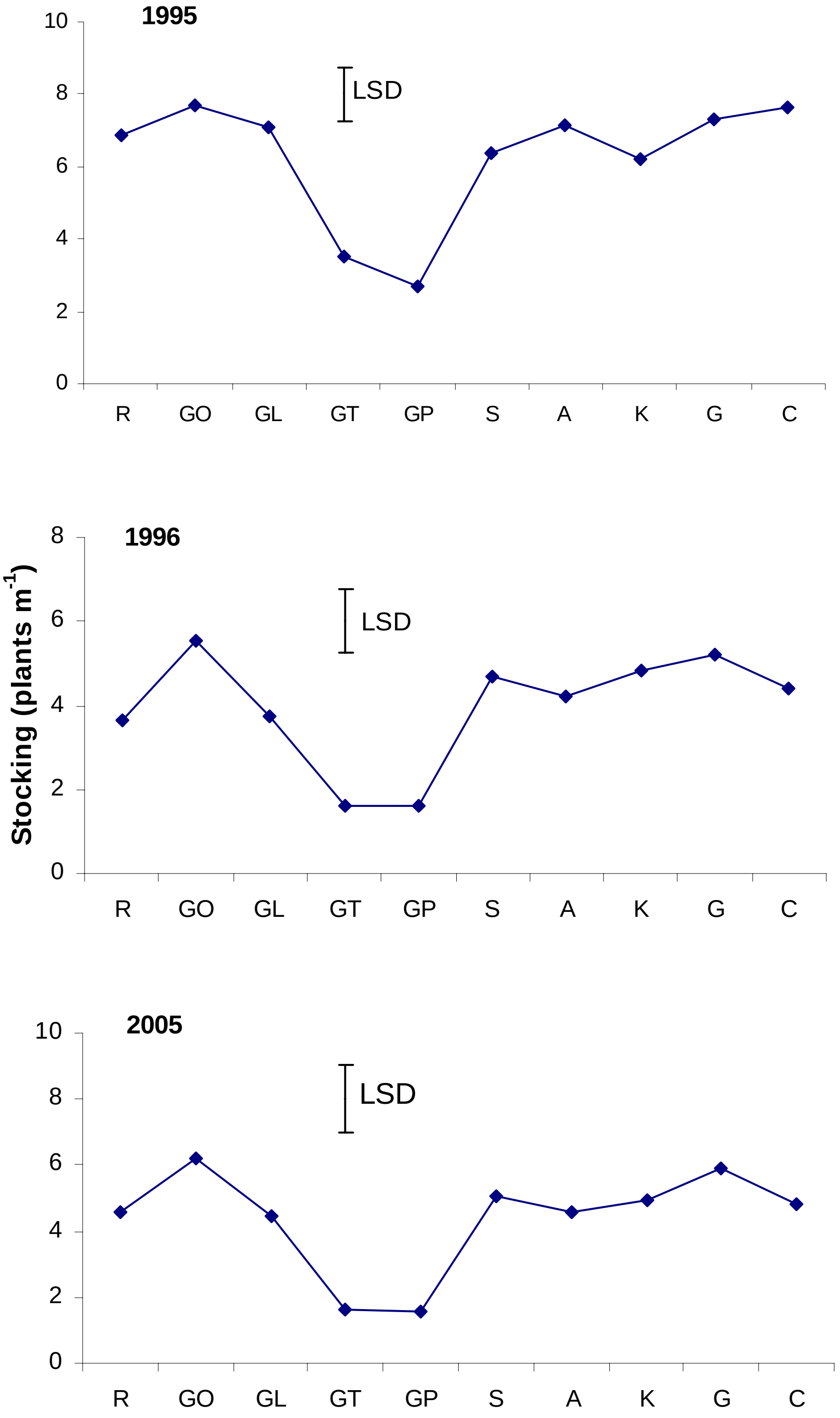


Fig. 6. Presowing treatment effects on stocking (all species combined) in 1995 (top), 1996 (middle) and 2005 (bottom). Treatment codes are as defined in Table 3. GT and GP significantly reduced stocking at each assessment, but stocking was not affected by other presowing herbicides. A line joining the points does not indicate that the x-axis is continuous.

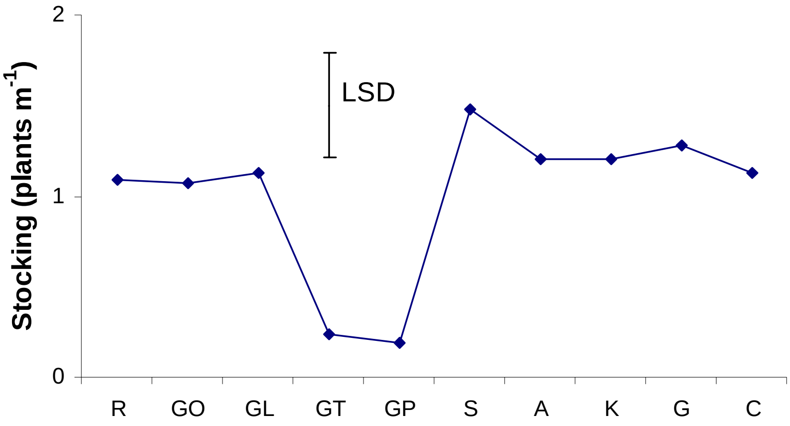


Fig. 7. Stocking of *Acacia dealbata* (Ad) in 1996; presowing treatments of GT and GP significantly reduced stocking.

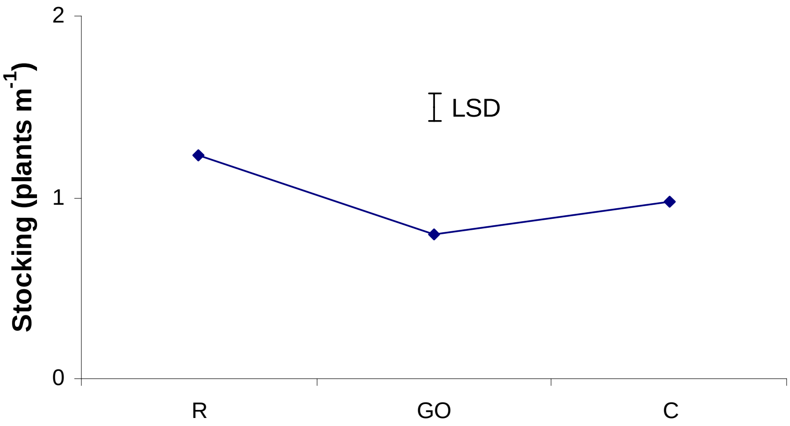


Fig. 8. Effects of oversprays of Roundup or GO on stocking of *Acacia dealbata* (Ad) in 1996; over spraying of GO slightly reduced stocking, and R slightly increased it.

The factorial design of Experiment 1 permitted a search for any interactions between the various presowing treatments and the oversprays. No significant interaction was detected for total stocking (all species combined) or for most species analysed individually, though several approached significance (Table 4). In one case only, *Acacia pravissima*, was there a significant interaction. The importance of this observation is not clear, but it is illustrated in Fig. 9. The results for the three oversprays diverge markedly where GL or G were used presowing but less so with the other presowing treatments.

There was a broad band of lower stocking diagonally through the experiment, possibly reflecting poorer drainage, but the control plots were well-enough placed to cover the variation (Fig. 10).

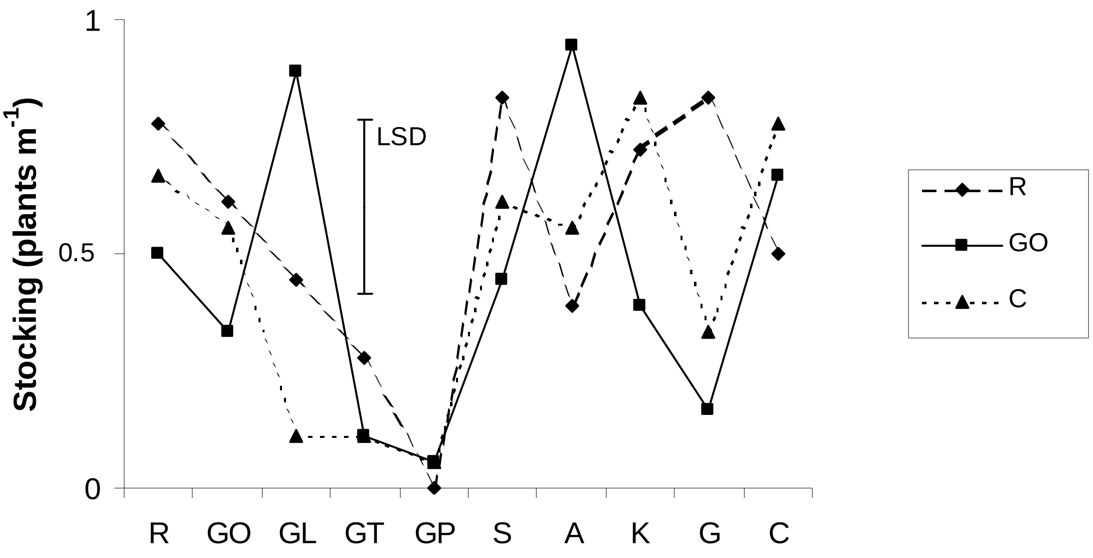


Fig. 9. Stocking of *Acacia pravissima* (Ap) in 1996. The effect of overspray seems to have depended on presowing treatment. For example, the strongest effect occurred with a presowing spray of GL, In this treatment only, stocking was lowest if there was no overspray (C) and highest after overspraying with GO.

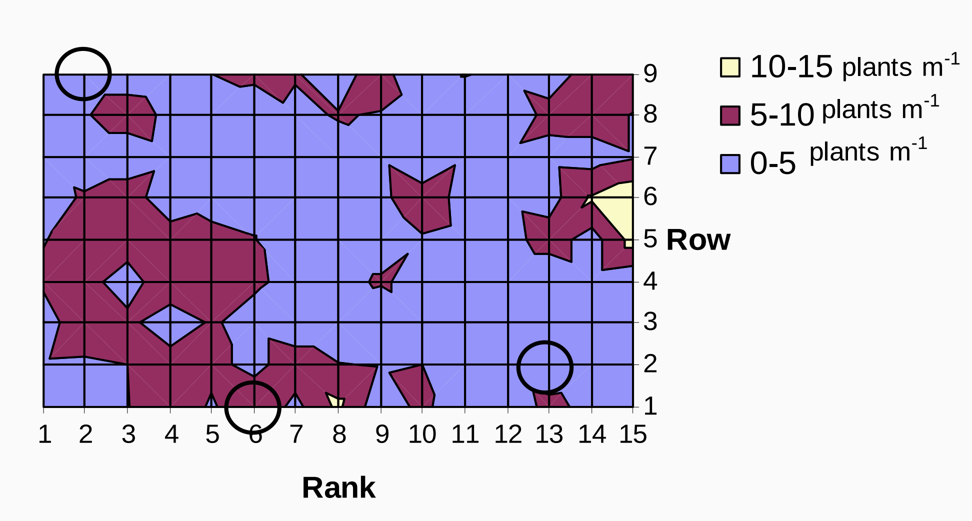


Fig. 10. A contour surface map of stocking in 2005; circles indicate the location of plots with combined presowing and overspray control treatments in Experiment 1. Note the broad area of lower stocking through the centre of the experiment.

Table 4. Significance of the main effects of presowing and overspray treatments and their interaction on stocking in 1995, 1996 and 2005 in Experiment 1. Results are presented only for those species for which an effect was statistically significant or approached significance (P<0.15), as well as for totals summed over all species. A P-value indicates the probability that treatment differences were due to uncontrolled variability rather than the treatments applied. Hence, the lower the P-value, the greater the certainty of an effect due to treatment.

Species		P-Value	
	Presowing	Overspray	Interaction
		1995	
Total	0.00		
Ad	0.00		
Ap	0.00		
ALv	0.00		
Ea	0.06		
Eo	0.00		
Ev	0.00		
Ls	0.01		
		1996	
Total	0.00	0.01	
Ad	0.00	0.03	
Amu		0.00	0.08
Ap	0.00		0.05
ALv	0.01	0.00	
Cp		0.02	
Eo	0.10		
Ep	0.04		
Et			0.12
Ev	0.00		
		2005	
Total	0.00	0.05	0.10
Ad	0.00	0.11	
Ame	0.00	0.14	
Amu	0.08	0.03	
Ap	0.01		0.09
Cr	0.15		
ALv		0.12	
Ev	0.01		
Eo	0.01		
Ea		0.15	
Et			0.11

Basal Area

Basal area was assessed only in 2005, ten years after sowing. Presowing treatment with GL, GT, GP and K significantly ($P < 0.01$) reduced basal area (totalled over all species, Fig. 11). Analysis of data for individual species showed that the reduction was most distinct ($P < 0.05$, Table 5) for *A. pravissima* and *E. ovata* and that, in the case of *E. ovata*, all presowing treatments lowered the average basal area significantly (Fig. 12). In this species, the average basal area was only 0.75 $cm^2\ m^{-1}$ (average of the treatments) if sprayed before sowing compared to 5.00 $cm^2\ m^{-1}$ if not sprayed then (Fig.12). The peculiarity of this result suggests it might be a statistical aberration that needs to be viewed with suspicion.

Overspraying had no significant effect on basal area and did not affect the responses to the presowing sprays (Table 5, $P > 0.05$ for all main effects and interactions). Average basal area across the site (both experiments) was 44.8 $m^2\ ha^{-1}$.

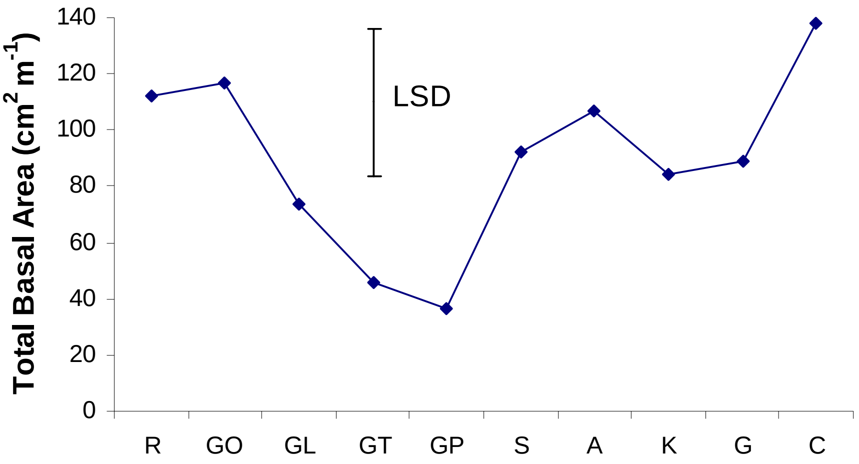


Fig. 11. Total (i.e. over all species) basal area of trees measured in 2005 in Experiment 1. Presowing treatments with GL, GT, GP and K significantly reduced basal area.

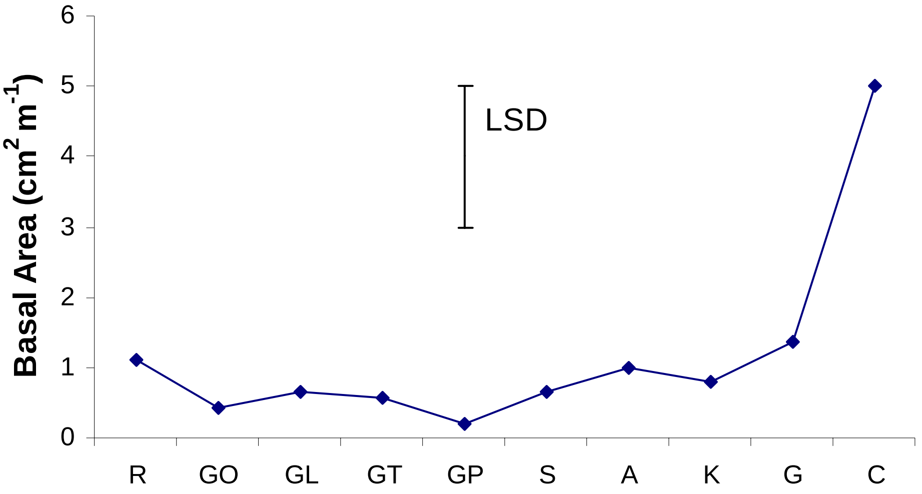


Fig.12. **Basal area of *Eucalyptus ovata* (Eo). All presowing spray treatments significantly reduced basal area of this species compared to the control.**

Table 5. Significance of the main effects of presowing and overspray treatments and their interaction on basal area in 2005 in Experiment 1. Results are presented only for those species for which an effect was statistically significant or approached significance (P<0.15), as well as for totals summed over all species.

Species		**P- Value**	
	Pre-sowing	**Over-spray**	**Interaction**
		2005	
Total	0.01		
Ad		0.14	
Amu	0.12		
Ap	0.02		
Ea		0.09	
Eo	0.00		
Ev		0.06	
Et			0.14

Dominant Species

There were no significant effects of presowing sprays, overspraying or their interaction on the diameter of the three biggest trees per plot (dominants). The biggest trees were *Eucalyptus amygdalina* (Ea), DBH = 10.4cm; *Eucalyptus viminalis* (Ev), DBH = 8.8 cm; and *Allocasuarina verticillata* (Alv), DBH = 7.7 cm (Fig. 13).The most frequent dominant species was *Acacia dealbata* (Ad) followed by four species of Eucalyptus (Fig 13).

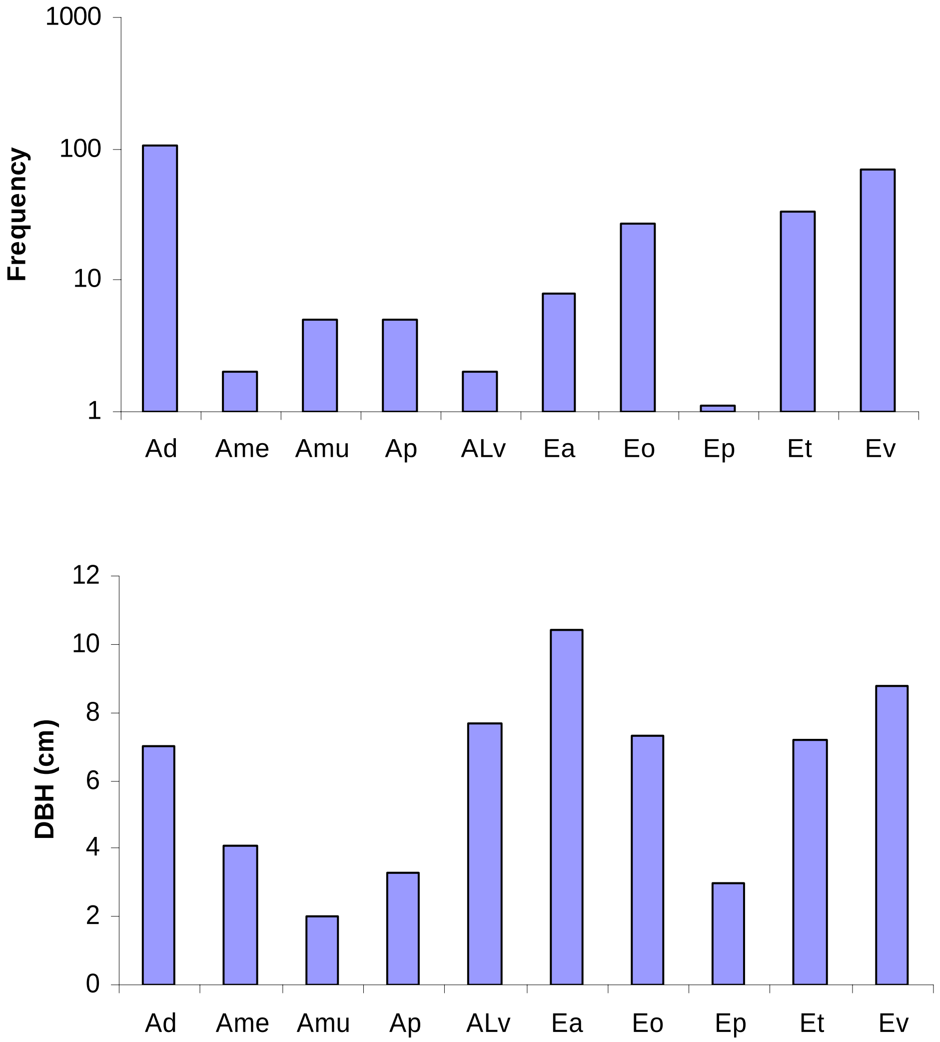


Fig. 13. Frequencies and sizes of the dominant species in Experiment 1 in 2005 (3 plants per plot assessed), combined across all treatments and plotted on a logarithmic scale. Size is indicated by mean diameter at breast height (DBH). Note the numerical dominance of *Acacia dealbata*, but the size dominance of *Eucalyptus amygdalina* (Ea).

Experiment 2: Oversprays Alone

Stocking

Measurements made in 1995 preceded the overspray treatments. Thus they were independent of those treatments and of potential use as covariates to improve the precision of comparisons made in Experiment 2. Analyses of covariance showed a strong correlation between values for 1995 and those for 1996 or 2005 for total stocking and for stocking of individual species (mostly $P < 0.05$). We therefore chose to use the 1995 measurements as covariates to improve sensitivity of the analysis for detecting the effects of overspraying treatment.

Some herbicides produced substantial increases in total stocking (all species combined). They were more distinct in 2005, nine years after overspraying, than they were in 1996, nine months after overspraying (Table 6, respectively $P < 0.05$ and $0.05 < P < 0.1$) The herbicides that caused significant ($P < 0.05$) increases at the assessment of 2005 were GL, GT, GP, AG, AS and K (Fig. 14). Analyses for individual species also showed augmentation of stocking of two species by some of these herbicides, though the effects were significant only in the 1996 assessment and not in the 2005 assessment; GL, GT, GP and K all augmented stocking of *Acacia mucronata* (Amu) (Fig. 15). Effects were similar on stocking of *Allocasuarina verticillata* (ALv) except that any effect of GL failed to reach significance (Fig. 16). The remaining overspray herbicides – R, GO, S, AG and AS – had no significant effect on stocking of any species or on total stocking (Fig. 14-16, Table 6).

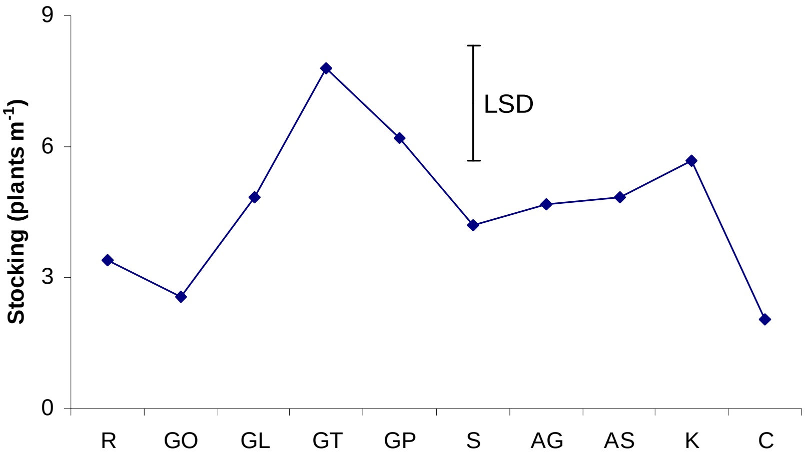


Fig. 14. Effects of oversprayed herbicides on total stocking (all species combined) in 2005. Stocking was lowest in the unsprayed treatment (C), and significantly augmented by GL, GT, GP, AG, AS and K.

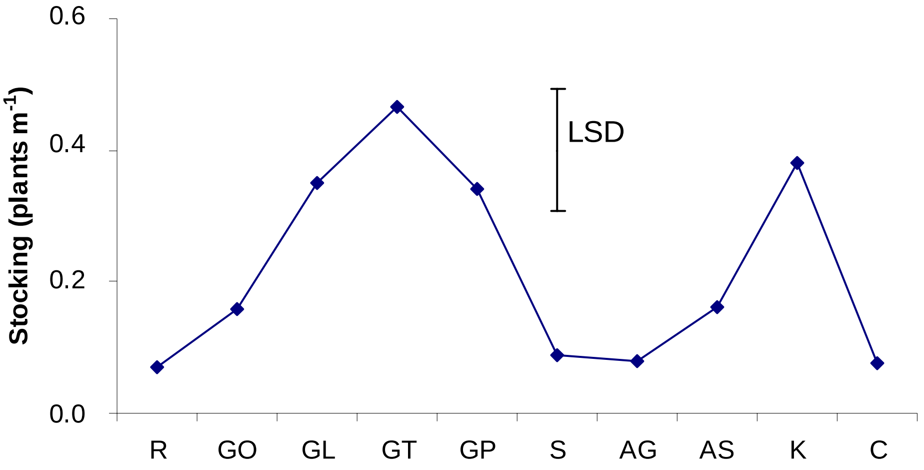


Fig. 15. **Effects of oversprayed herbicides on stocking of *Acacia mucronata* (Amu) in 1996. Stocking was significantly augmented by GL, GT, GP, and K.**

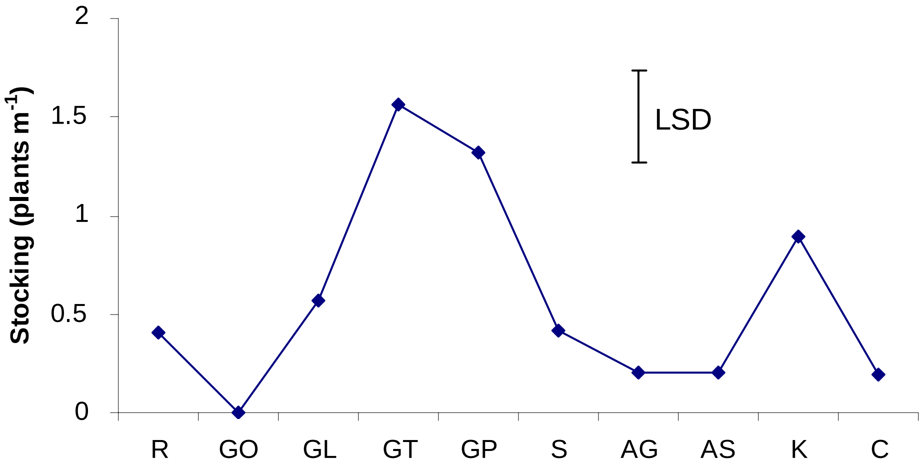


Fig. 16. **Effects of oversprayed herbicides on stocking of *Allocasuarina verticillata* (ALv) in 1996. Stocking was significantly augmented by GT, GP, and K.**

Table 6 . Significance of the effects of overspray treatment on stocking in 1996 and 2005 in Experiment 2. Results are presented only for those species for which an effect was statistically significant or approached significance (P < 0.15), as well as for totals summed over all species.

Species	P-Value
	1996
Total	0.07
Amu	0.02
ALv	0.00
Ep	0.06
Ev	0.14
	2005
Total	0.03

Basal Area

Basal area was assessed only in 2005. Some oversprayed herbicides (R, GO, GP, and S) led to substantial, statistically significant (P < 0.05) increases in the basal area of *Eucalyptus viminalis* (Ev) (Fig. 17). There were no significant effects of overspray herbicides on the basal area of other species (Table 7) or on total stocking (all species combined).

The application of oversprays in Experiment 2 was interrupted, by rain. Oversprays applied 6th to 8th June 1995, were R, GO, GT, GP and S. Others were applied later and completed by 26th July 1995. The effect of different times of application is unknown, but because conditions were cool, no great timing effect would have been expected.

Table 7. Significance levels of the effect of overspray treatments on basal area in 2005 in Experiment 2. Results are presented only for those species for which an effect was statistically significant or approached significance (P < 0.15).

Species	P-Value
Amu	0.12
Ev	0.02

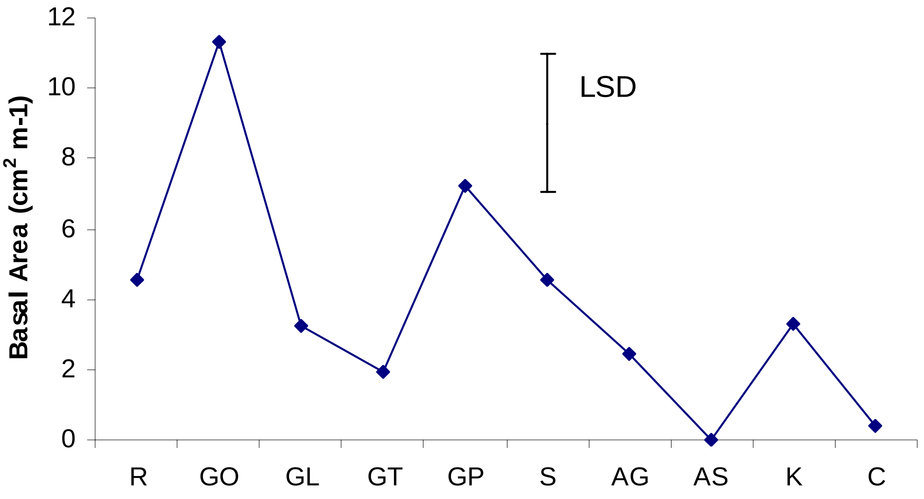


Fig. 17. Effects of oversprayed herbicides on basal area of *Eucalyptus viminalis* (Ev) in 2005. Overspraying with R, GO, GP and S significantly increased basal area.

Dominant Species

As in Experiment 1, there was no significant effect of oversprayed herbicides on the DBH of dominants.

DISCUSSION

This shelterbelt was successfully established, and being dense, tall (10 m) and wide (20 m) after 11 years it provided excellent shelter from wind. The reasons for success are probably a combination of the high seeding rate and adequate weed control prior to and during the first year of the experiment. Despite several years of below-average rainfall during the experiment, and the generally cold, dry conditions, self-thinning of established plants was minimal and most plants on this site seemed healthy. However, self thinning is likely to continue, because the stocking (20,000 plants ha^{-1}) and BA are at levels considered excessive even for commercial plantations on higher rainfall sites. Even at a much lower stocking, competition can be severe. For example, at three sites in eastern Australia that had up to 6,569 acacias ha^{-1}, there was a decrease of up to 82% in the stem volume of crop trees that were at a stocking of c. 1,900 trees ha^{-1} (Turvey et al. 1983). This effect was probably mainly due to competition for water. That drought deaths in our site were not more severe indicates that the native species chosen for direct seeding were quite drought tolerant and hence well-adapted to the site.

Competition between tree seedlings and weeds is a problem in plantation forests generally, because it reduces the availability of nutrients, water and light for tree growth (Sands and Nambiar 1984, Smethurst and Nambiar 1989, Lowery et al. 1993). Tasmania is no exception (Adams et al. 2003, Mendham et al. 1999), and it might be even more serious in direct-seeded, revegetation projects. If such competition reduces resource availability to a limiting level, tree mortality can increase and growth rates decrease. The most common method of weed control utilises manufactured synthetic chemicals known as herbicides. Other forms of weed control are mulching (shading) and mechanical, e.g. slashing, mowing and cultivation, but the latter requires soil disturbance that can damage roots if trees are already established.

A method of classification of herbicides is based on the timing of application with regard to the stage of crop or weed development. Timing depends on many factors, including the chemical class of the material and its persistence, the crop and its tolerance to the herbicide, weed species, cultural practices, climate, soil type and soil condition. The categories of timing are *pre-emergence (residual)* and *post-emergence (knockdown).* Pre-emergence applications are completed prior to emergence of the crop or weeds. Post-emergence applications are made after the crop or weed emerges from the soil (Ware 1999).

Gesatop (GT, a.i. simazine) and Gesaprim (GP, a.i. atrazine), which both reduced stocking in at our site, have been used extensively in forest plantation establishment in Australia. GT only acts as a residual, but the GP has both knockdown and residual activity. GP is significantly more soluble and mobile, which translates to higher environmental risk (risk of contaminating water resources) and lower usage in recent years in the forestry sector.

Our findings that GT and GP applied before sowing reduced stocking and basal area are broadly consistent with those of Fagg (1988) who found that GT decreased stocking of *Eucalyptus regnans* seedlings that were planted into former pasture. However, our experiments show the damaging effect at a lower application rate. The rate of 6 L ha^{-1} GT caused much damage in Experiment 1, but not in that of Fagg (1988). He observed damage only at 12 L ha^{-1}, a rate used in some plantation forests currently. Some work suggests that the more standard rate of 8-9 L ha^{-1} GT is too high for sandy soils (Tomkins pers. comm.)

The other herbicides tested presowing, i.e. R, GL, S, AS, K and G, did not significantly affect stocking in our experiments. However, some caution is needed, because Hall and Burns (1991) found that pre-emergent applications of S led to higher tree mortality when applied at higher rates (10-20 L ha^{-1} product) than we used. Campbell and Nicol (1998) found that some native species had reduced survival with pre-emergent applications of GO and GP. We also found that most of these herbicides reduced basal areas. This result suggests a phytotoxic effect on the emerging plants of the seeded species that outweighed any positive effect of reduced weed competition. This effect highlights the compromise required when choosing the rate at which to use a herbicide, i.e. effectiveness against target weeds versus potential phytotoxic effects on species to be retained.

Phytotoxicity might have been revealed in our experiments because, under our conditions, the experimental herbicides may have contributed little or no extra weed control beyond that provided by the pre-experiment sprays of R. The knockdown activity (where present) may have added little because at presowing there were very few live plants anyway. The residual activity (where present) also may not have extended weed control substantially at the rates that we used. We did not make any measurements of weed growth but did observe substantial return of weeds during the first year of the experiment.

In short, our results with herbicides applied 2 weeks before direct-seeding into weed-free conditions, did not indicate any advantage of using the additional herbicides presowing. On the contrary, GT, GP and GL were damaging. We therefore agree with Tomkins (2003) that residual herbicides should be used with care when direct-drilling, even though Fagg (1988) found that tree growth was promoted if he included a pre-emergent herbicide along with the knockdown herbicide.

Fagg (1988) suggested using knockdown herbicides such as R, GL and A to achieve weed-free conditions prior to direct seeding. We have reservations about the GL and A, because A reduced total basal area in Experiment 1.

Several studies have recommended Roundup for pasture weed control prior to planting eucalypts. A good combination during plantation establishment is R with GT or GP. However, these last two herbicides should be applied with caution prior to direct-seeding. As in our experiments, Bird et al. (2002) found that GO, K, GL and GP can increase the stocking of some direct-seeded native trees when scalping is used. Scalping of a narrow band, as used in the current study, is important because it reduces the likelihood of the seeded species contacting the pre-emergent herbicide.

In the present study, the effects of herbicides applied as oversprays were quite different from when applied presowing. Oversprayed herbicides generally increased stocking significantly, whereas, they either had no effect or reduced stocking if applied presowing.

The sharpest difference was the case of the triazine herbicides, GP and GT. If applied presowing, they sharply reduced stocking but as oversprays (in both cases at a rate of 6 L ha^{-1}) they significantly increased stocking. It seems that these herbicides (when applied presowing) killed trees during the first few months despite the removal of the herbicide from the immediate vicinity of the seedlings by scalping of the narrow band of soil into which the seeds were sown. Root uptake by direct-seeded plants might occur if the herbicide leached below the scalping depth prior to scalping or when the growing roots extend into the unscalped area. In the contrasting case of overspraying, any toxicity of simazine and atrazine on established trees appears to have been slight; and more than compensated by the reduction in competition arising from their toxicity to weeds that appeared in the 9 months between sowing and overspraying, or germinated during the first few months post-spraying.

Fagg (1988) found that GP applied at a high rate (12 L ha^{-1} GP, as currently used in some plantation forests) to unshielded trees (i.e. as an overspray) retarded height growth and contributed to high mortality (16-42%). We did not find such determintal effects on survival and growth, possibly because rates of these herbicides used in the current experiment were lower. Brandi et al. (1977) found that the herbicides favouring survival in *Eucalyptus spp,* when used as oversprays were GO, K, and S, but that GT decreased stocking. This tolerance or phytotoxicity will probably vary with the method of application, mode of absorption by plants (root versus shoot), soil mobility and temperature (greater tolerance in colder conditions). Hence, there have been variable outcomes from earlier studies using triazine herbicides, and ours is a case where oversprays of GT and GP did assist in establishment.

Our results suggest R, GL, GT, GP, AS, K, GO and S can be applied post-sowing without having any detrimental effect on stocking. However, GT, GO and Srflan are mainly residual herbicides that would not completely control weed competition unless combined with a knockdown herbicide. In addition, Brandi et al. (1977) suggest that some herbicides such as Dual, Metribuzin, Enide and Oust can be used as overspray treatments to increase stocking of direct-seeded species.

It is counter-intuitive to suggest that a broad-spectrum, knockdown herbicide such as R can be used as an overspray, but our results suggest a rate of 1 L ha^{-1} (product) is safe. Tomkins (2003) also indicates that Roundup can be used as an overspray after direct-seeding, but suggests an even lower rate should be used (0.7 L ha^{-1}). Campbell and Nicol (1998) found that even though the effect was age and rate dependent, mortality was 34-99% of unsprayed controls when low rates of R (0.2 L ha^{-1} product) were applied at 5 months of age, and mortality was higher with earlier or higher rates of application.

Species can differ in their response to herbicides and their combinations. Basal area of some species decreased when GL, GT, GP and K were used in presowing treatments, and it was insignificant when R and GO are used as oversprays. However, for *Eucalyptus viminalis,* when R, GO, GP and S were used only as oversprays, basal area seemed to increase. Results indicate that *Acacia dealbata, A. mucronata, A. pravissima, Allocasuarina verticillata, Callistemon pallidus, Eucalyptus amygdalina, E. ovata, E. tenuiramis* and *E. viminalis* grew well, especially the acacias. A reason for this result could be that these species were better adapted to the site conditions. In contrast, *Allocasuarina littoralis, A. monilifera, Banksia marginata, Bursaria spinosa, Callistemon viridiflorus, Callitris oblonga, C. rhomboidea, Eucalyptus johnstonii, E. rodwayii, Lepstospermum lanigerum* and *L. scoparium* were not recorded at all or only sparsely in 1995 and 1996. The non-growth of these trees could have been because they were poor competitors, they had a low germination rate, or they were not adapted to the environment at this site. Another factor is soil fertility; plants often grow better if fertilisers are applied, but no fertilizers were used in this experiment.

Total basal area and growth of dominants was less sensitive to treatment than stocking, possibly because the very dense stocking and minimal buffering would have led to plot neighbour effects that tended to even out growth differences between treatments. Similar experiments in the future would benefit from larger plots and buffers.

CONCLUSIONS

- Adequate weed control and a high seeding rate underpinned the successful establishment of this shelterbelt, which, at 11 years of age is highly effective with 20,000 plants ha^{-1}, mean basal area 44.8 m^2 ha^{-1}, and mean dominant height 10 m.

- The largest species at 11 years were *Eucalyptus amygdalina, E. viminalis* and *Allocasuarina verticillata. Acacia dealbata* was the most abundant species, even though it made up only 2% of the numbers of seeds sown.
- The site was weed-free at sowing, but pasture weeds regrew during the first few years prior to being totally suppressed by the dense stand of sown species.
- Simazine (Gesatop) and atrazine (Gesaprim) applied before sowing reduced stocking significantly. The seven other herbicides tested did not.
- Over-spray treatments of all herbicides tested did not significantly reduce stocking, and in some cases significantly increased it, i.e. when Glean, Gesatop, Gesaprim, Agrapop and Kerb were used.
- After 11 years, BA was lowest where Glean, Gesatop, Gesaprim and Kerb were used pre-sowing, but there were no significant negative effects on BA when sprayed with Round-up or Goal as over-spray treatments. Otherwise, BA generally increased with over-spray treatments.
- Results from this and other research provide guidance on the type and rate of herbicide to use during shelterbelt establishment.

RECOMMENDATIONS

1. Direct-seed only into weed-free conditions.
2. On sites similar to this study, consider using *Acacia dealbata*, *A. melanoxylon*, *A. mucronata*, *A. pravissima* (non-native), *Allocasuarina litorallis*, *Callistemon pallidus*, *Eucalyptus amygdalina*, *E. ovata*, *E. tenuiramis* and *E. viminalis*.
3. Use only residual herbicides when there are no living weeds, but, if this is prior to sowing, use only those that are effective against the weed species and tolerated by the sown species. If weeds are already established, herbicides with a knockdown effect are required.
4. Pre-sowing herbicides: In a direct-seeded shelterbelt using the same species as those in this experiment, and under similar growing conditions, do not use Gesaprim and Gesatop pre-sowing. Instead, use Roundup for mainly a knockdown effect in combination with Goal, Surflan, Kerb or Gesagard for a residual or dual effect.

5. Overspray herbicides: When spraying over established plants, use Glean or Asulox as a knockdowns. Also consider Roundup as a knockdown, but test it first. Gesatop can be used as a residual, or Agrapop or Kerb for a dual effect.
6. More research is needed to fine-tune the rate and timing of herbicide applications (particularly as oversprays) in relation to selectivity against pasture weeds in favour of sown native species. Seeding rate in relation to herbicide use also needs to be investigated as a factor that influences the competitiveness of weeds and therefore the rate of attainment of shelterbelt effectiveness.

ACKNOWLEDGMENTS

The authors thank Neil Davidson and Mike Castley for helping to identify the species, Craig Baillie for help with measurements, Chris Barnes for advice on chemicals, Axel Meiss, Jonathan Duddles, and Chris Beadle for advice and assistance, and Barry Tomkins for comments on an earlier draft.

REFERENCES

Adams, P.R., Beadle, C.L., Mendham, N.J. and Smethurst P.J. (2003) The impact of timing and duration of grass control on growth of a young *Eucalyptus globulus* Labill. plantation. New Forests 26:147-65.

Bird, P.R., Kearney, G.A. and Cumming, K.N. (2002) Early work with herbicides applied to direct-seeding of trees before sowing and as oversprays in the following year. Paper presented to Plantation Weed Control Workshop and Seminar, Hamilton, Victoria, February 2002 (Convenor I.B. Tomkins).

Brandi, R. M., Couto, L., Silva, J. F., Miyasaki, J. M., (1977) Tolerância de diversas espécies de Eucaliptos a alguns herbicidas. Revista Árvore 1(2):149-153.

Campbell, M.H. and Nicol, H.I. (1998) Tolerance of tree seedlings to pre- and post-emergence herbicides. Proceedings 9th Australian Agronomy Conference ‘Agronomy, Growing a Greener Future’ 4 pp. (http://www.csu.edu.au/special/agronomy/papers/53/53.html).

Churchill, K. (2004) The effect of ‘Eucamix’ granular herbicide on a range of non-commercial tree species. An evaluation of the feasibility of using a selective residual herbicide in a revegetation trial. CRC-SPF Technical Report No. 150, 4p.

Close, D. C. (2002) A study tour of south-west Western Australia and the Armidale Tablelands: Trees decline, revegetation and farm forestry. CRC – SPF Technical Report. No. 87, 12pp.

Close, D.C. and Davidson, N.J. (2001) A synthesis of rural tree decline and revegetation research, vegetation establishment and species selection survey, and description of future research. CRC-SPF Technical Report No. 76, 46p.

Close and Davidson (2002) Revegetation to combat tree decline in the Midlands and Derwent Valley Lowlands of Tasmania: practices for improving plant establishment. Ecological Management and Restoration 4:29-36.

Fagg, P. C. (1988) Weed control techniques for the establishement of *Eucalyptus regnans* plantation on pasture sites. Australia Forestry 51:28-38.

Hall, M. (1986) Post emergence weed control in a radiata pine nursery with four selective herbicides. Australian Forestry 49(3):155-9.

Hall, M. and Burns, M. (1991) Weed control among planted and direct-seeded *Eucalyptus, Acacia and Casuarina* with the herbicides diphenamid, orylazin, clopyralid and fluaziflop-butyl. Australia Forestry 54(2):16-22.

Lowery, R. F., Lambeth, C. C., Endo, M., and Kane, M. 1993. Vegetation management in tropical forest plantations. Canadian Journal of Forest Research 23:2006-2014.

Mackay, S.J. (19 78) Dying eucalypts of the New England Tablelands. Forest and Timber 14:18-20.

Mackay, S.M., Humphreys, F.R., Clark, R.V., Nicholson, D.W., and Lind, P.R. (1984) Native tree dieback and mortality on the New England Tablelands of New South Wales. Research paper No. 3. Forestry Commission of NSW, Sydney.

Marchi, S.R., Pitelli, R.A., Bezutte, A.J., Corradinel, L., and Alvarenga, S.F. (1995) Efeito de períodos de convivência e de controle das plantas daninhas na cultura de *Eucalyptus grandis*. Seminário sobre Cultivo Mínimo no Solo em Florestas, 1, Curitiba, 1995. Anais. Piracicaba: CNPF/IPEF/UNESP/SIF/FUPEF. pp.122-33.

Mendham, N., Baker, S., Dingle, J., Smethurst, P., Beadle, C., Neilsen, W., Borger, J., Adams, P., Holz, G., Barnes, C., Hetherington, S., Naughton, P., and Appleton, R. (1999). Impact of competition from weeds on early growth of eucalypts and pines at five sites in Tasmania and Victoria. *In:* Ellis RC and Smethurst PJ (eds) *Practising Forestry Today. Proceedings,18th Biennial Conference of the Institute of Foresters of Australia,* Hobart, Tasmania, 3-8 Oct. 1999. pp. 186-7.

Naldolny, C. (1984) Eucalypt dieback on the Northern Tablelands of NSW. MSc. Thesis, University of New England, Armidale.

Neyland, M. (1996) Tree Decline in Tasmania. Land and Water Management Council, Hobart, pp 44.

Parker, J.N. (1994) The plight of planted eucalypt: Evening the odds. Biennial Conference of the Australian Forest Growers, Faces of Farm Forestry, Launceston, Tasmania.

Parsons, T. (1999) Direct Seeding Program. Greening Australia Technical Note, Hobart, Tasmania.

Pinkard, E.A. (1992) Ecological impediments to the establishment of trees by direct seeding on pastoral sites in the Midlands of Tasmania. MSc Thesis, University of Tasmania.

Rees, S. (2000) Understanding Rural Tree Decline in the Midlands, Tasmania. Honours Thesis, University of Tasmania.

Sands, R. and Nambiar, E.K.S. (1984) Water relations of *Pinus radiata* in competition with weeds. Can. J. For. Res. 14:233-237.

Smethurst, P.J. and Nambiar, E.K.S. (1989) Role of weeds in the management of nitrogen in a young *Pinus radiata* plantation. New Forest 3:203-224.

Spanswick, S. and Zund, P. (1999) Longford soil Report. Reconnaissance Soil Map Series of Tasmania. Department of Primary Industries Water and Envirnmental, Tasmania, and Natural Heritage Trust (A Revision of Division Report 15/57 Longford by K. D. Nocolls, CSIRO Division of Soils, Adelaide, 1959).

Tomkins, I.B. (2003) Weed control in establishing native tree species. Plant Protection Quarterly 82(2):80-82.

Turvey, N.D., Attiwill, P.M., Cameron, J.N. and Smethurst, P.J. (1983) The growth of planted pine trees in response to variations in the densities of naturally regenerated acacias. For. Ecol. Manage. 7:103-117.

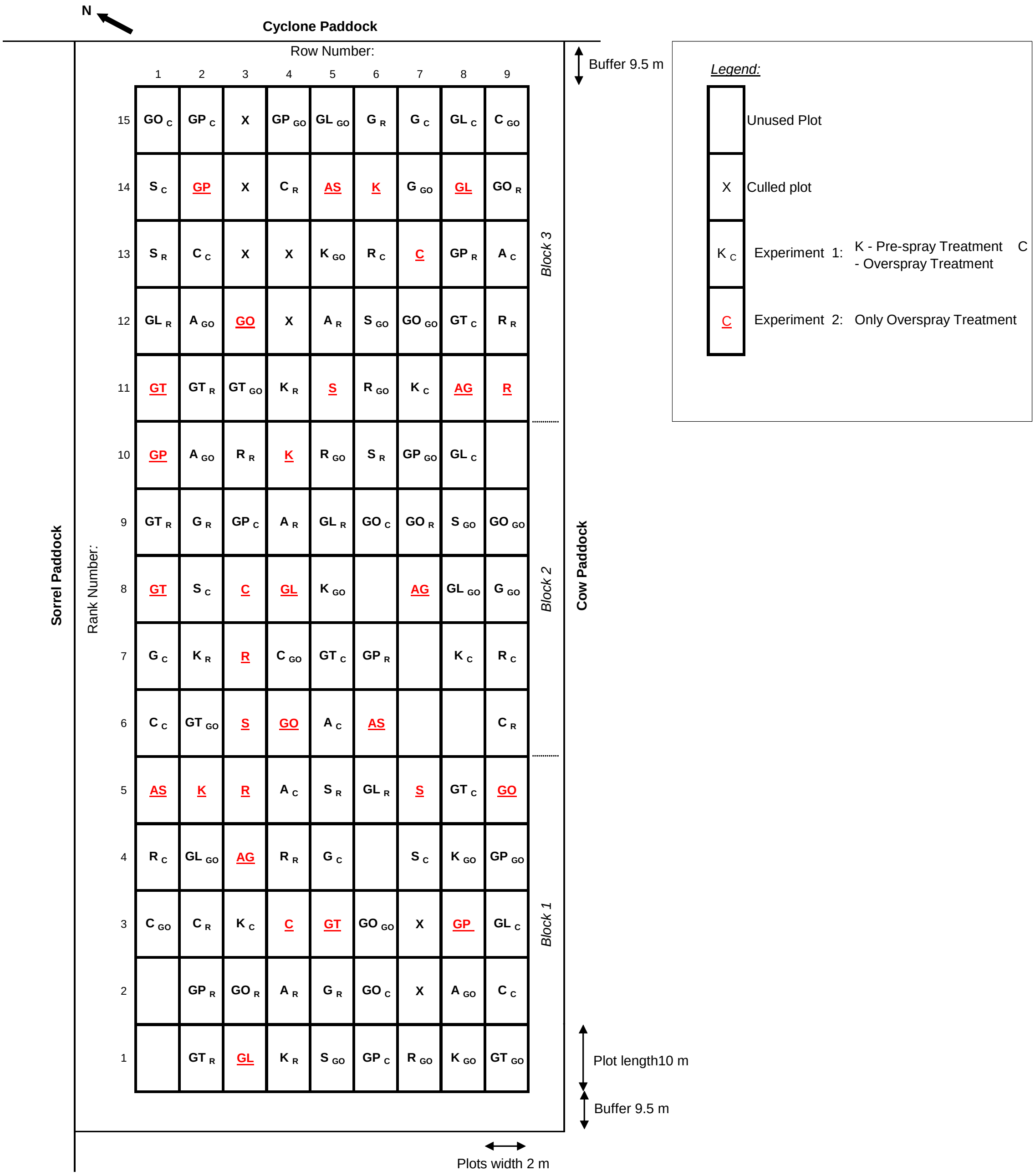
Ware, G.W. (1999) An Introduction of Herbicides. Radcliffe's IPM world Textbook. University of Minnesota.

APPENDIX 1

The location of the site is indicated by and arrow and elipse in the Cow Paddock.

APPENDIX 2

LAYOUT OF EXPERIMENTAL PLOTS



Rank Number: \ Row Number:	1	2	3	4	5	6	7	8	9
15	GO_{C}	GP_{C}	X	GP_{GO}	GL_{GO}	G_{R}	G_{C}	GL_{C}	C_{GO}
14	S_{C}	GP	X	C_{R}	AS	K	G_{GO}	GL	GO_{R}
13	S_{R}	C_{C}	X	X	K_{GO}	R_{C}	C	GP_{R}	A_{C}
12	GL_{R}	A_{GO}	GO	X	A_{R}	S_{GO}	GO_{GO}	GT_{C}	R_{R}
11	GT	GT_{R}	GT_{GO}	K_{R}	S	R_{GO}	K_{C}	AG	R
10	GP	A_{GO}	R_{R}	K	R_{GO}	S_{R}	GP_{GO}	GL_{C}	
9	GT_{R}	G_{R}	GP_{C}	A_{R}	GL_{R}	GO_{C}	GO_{R}	S_{GO}	GO_{GO}
8	GT	S_{C}	C	GL	K_{GO}		AG	GL_{GO}	G_{GO}
7	G_{C}	K_{R}	R	C_{GO}	GT_{C}	GP_{R}		K_{C}	R_{C}
6	C_{C}	GT_{GO}	S	GO	A_{C}	AS			C_{R}
5	AS	K	R	A_{C}	S_{R}	GL_{R}	S	GT_{C}	GO
4	R_{C}	GL_{GO}	AG	R_{R}	G_{C}		S_{C}	K_{GO}	GP_{GO}
3	C_{GO}	C_{R}	K_{C}	C	GT	GO_{GO}	X	GP	GL_{C}
2		GP_{R}	GO_{R}	A_{R}	G_{R}	GO_{C}	X	A_{GO}	C_{C}
1		GT_{R}	GL	K_{R}	S_{GO}	GP_{C}	R_{GO}	K_{GO}	GT_{GO}

Legend:

	Unused Plot
X	Culled plot
K_{C}	Experiment 1: K - Pre-spray Treatment C - Overspray Treatment
C	Experiment 2: Only Overspray Treatment