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Direct seeding trees on farmland in the Western Australian wheatbelt

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ABSTRACT

Successful establishment of trees on farmland by direct seeding is dependent on a number of factors. To date, little research on direct seeding has been conducted in the Western Australian wheatbelt. Field and nursery experiments were conducted to determine suitable species, weed control methods, sowing times and seeding techniques. Analysis of these experiments was based on successful establishment of seedlings sown from seed and surviving the first summer.

Sowing time was the most significant variable evident in the field experiments. Trees sown in the winter months of June and July out-performed later sowing times. Early sowing of trees in areas of low seasonal rainfall appears to offer considerable advantages for successful establishment over late sowing.

Despite variable results, the testing of a number of chemical and mechanical weed control treatments failed to produce a clear method to be used with direct seeding in wheatbelt conditions. Likewise, no preference was gained from testing a number of direct seeding techniques. However, large-seeded *Acacia* species performed better when sown with a 5-10 mm covering of soil, particularly at the site east of Narrogin. Smaller-seeded *Eucalyptus* species also performed better when covered by 2-5 mm of soil at most sites.

Local tree species performed best and were most reliable for direct seeding, although performance of individual species was affected by treatment and site combinations. Rock casuarina *(Allocasuarina huegeliana)* produced the highest relative establishment rate and the best real seedling survival rate of all species. York gum *(Eucalyptus loxophleba)* was the best performed eucalypt at all sites, while wandoo *(E. wandoo)*, tuart *(E. gomphocephala)* and pricklybark *(E. todtiana)* performed well at different sites. *Acacia* species were widely used in the experiments but only performed well in waterlogged saline soils at the site east of Narrogin.

INTRODUCTION

Direct seeding is a generic term for sowing native tree and shrub seeds into prepared ground as a method of direct plant establishment, using agricultural combine or specialized sowing equipment. Direct seeding is now recognized in Western Australia (WA) as a practical and cost-effective way to establish large numbers of trees on farms (Grewer 1988). Direct seeding is also used by government departments and private companies for revegetating road sides (Walden 1982) and old minesites (Brooks and Jeffries 1990).

The **wheatbelt** is a widely used description of the drier part of the WA agricultural ecosystem (Pigott 1993) which has 250-600 mm total annual rainfall, falling mostly in the winter months (Fig. 1). It is not a well-defined natural region and has highly variable soils, climate and vegetation (Gentilli, cited in Saunders and Curry 1990). As the name suggests, most of WA's wheat production is found in the wheatbelt along with a variety of cereal and legume crops mixed with grazing (Castle 1992).

Approximately 440 000 ha of farmland in the WA wheatbelt is affected by dryland secondary salinity, increasing at an estimated rate of 18 000 ha yr^{-1} (Schofield *et al.* 1993). Salinity is only one of many forms of land degradation, including soil erosion and acidity (Castle 1992). The clearing of native vegetation, primarily eucalypt woodlands, and the ongoing decline of remnants is accepted as the primary cause of land degradation in south-west WA (Pigott 1993; Schofield *et al.* 1993).

Integrated land-use planning, management of remnant vegetation, and effective revegetation of fragmented agricultural landscapes (Hobbs and Saunders 1991) can alleviate these threats and return the land to productive use. Other important benefits of revegetating old farmland include the restoration of aesthetic values to local landscapes, provision of wildlife habitat and corridors, and the maintenance of biological diversity (Hobbs 1993).

Revegetation of farmland using seedlings raised in nurseries has been too costly and time-consuming for many landholders. Planting and tending tree seedlings is labour intensive, even when machinery is used. Direct seeding techniques can be used to revegetate large areas of cleared land for as little as one-tenth the cost of planting seedlings (Grewer 1988). Use of farm machinery such as tractors and seeding combines allows farmers to direct-seed using familiar techniques. However, direct seeding is inhibited by lack of information concerning weed control, soil preparation, species selection and requirements. Generally there has been a lack of rehabilitation research in Australia (Malcolm 1990) despite recognition of land degradation problems (e.g. WA Parliament 1990).

A conference on direct seeding, titled *Sowing the Seeds*, provided a number of reviews, discussions and observations of current direct seeding practice in Australia (Greening Australia 1990). Direct seeding practices in WA were reviewed, with particular emphasis on the development of techniques for revegetating roadsides (Loney 1990).

Observations and case histories of direct seeding old farmland in the southern and south-coast areas of the wheatbelt have been recorded by Grewer (1988), Brown (unpublished data), Goff[1] (personal communication) and McDonald[2] (personal communication).

An extensive review of direct seeding techniques and experience in the WA wheatbelt has been prepared by Greening WA (Runciman[3] personal communication). Farmers, government advisers and scientists, and community groups were widely consulted on direct seeding practices using questionnaire, interview and discussion at public workshops. Broad regional recommendations resulting from the project have been made for direct seeding trees and shrubs on farmland (Greening WA 1992).

This review and consultation process revealed that little information was available about the effect on direct seeding results of a number of factors, namely: ground preparation, depth of sowing and seed size, weed control, and sowing time. These factors were considered likely causes of seedling establishment and survival[4] problems. Field and nursery experiments were devised to test these factors in a program of direct seeding research instigated at Narrogin and three other wheatbelt locations, Badgingarra, Jerramungup and Shackleton (Fig. 1).

This paper provides analysis and an integrated summary of that research program. It is envisaged that the results will provide a better understanding of the complex factors affecting the revegetation of farmland.

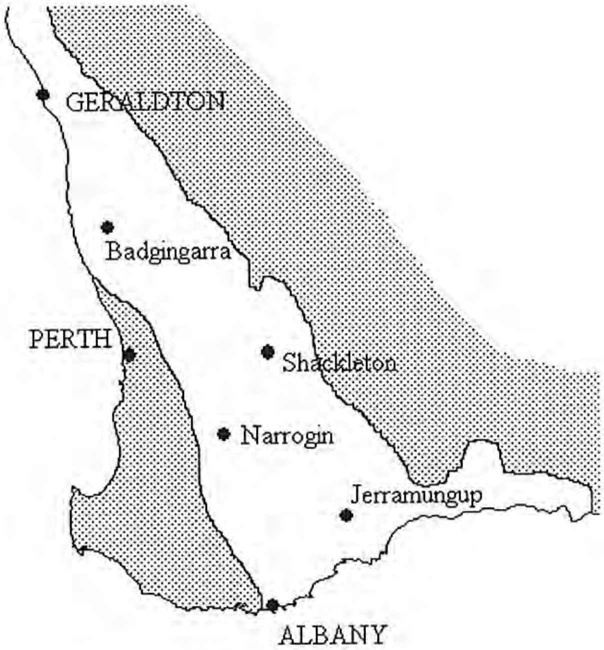

Figure 1. Map of south-west Western Australia indicating the wheatbelt (not shaded) showing sites mentioned in the text.

A review of factors affecting the rehabilitation of degraded farmland has recommended that several steps be followed for successful revegetation (Malcolm 1990). These include site characterization, site preparation, species selection, seeding techniques and protection from predators. Similarly, Loney (1990) has proposed stages for direct seeding operations - the four P's 'Planning, preparation, planting and protection'. Aspects of these factors are discussed in the analysis of these experiments, with special reference to weed control, sowing methods, sowing time and species selection.

NARROGIN DIRECT SEEDING EXPERIMENT

Background

Research was needed to provide local information about direct seeding trees to revegetate farmland in the southern part of the WA wheatbelt. An experiment was designed to investigate the importance of sowing time and weed control for the direct seeding method of tree establishment. A range of trees commonly planted on farms in the area were used. The experiment was repeated for three consecutive years to verify results, which are known to be complicated by seasonal conditions, especially rainfall.

The experiment was established in 1984 by the WA Department of Agriculture (WADA) at Narrogin.

[1] Jason Goff conducted a direct seeding trial on farmland near Highbury (unpublished).

[2] Denis McDonald conducted a direct seeding trial on farmland near West Arthur (unpublished).

[3] Helen Runciman was Direct Seeding Project Officer for Greening WA in 1991 and compiled an extensive report on information available and former surveys. With the exception of a recommmendation booklet (Greening WA 1992) this report has not been published.

[4] Two terms used throughout this paper require clarification: **establishment** is a general term that refers to the successful growing of a plant after it has germinated from seed and emerged from the soil with its first leaves; **seedling survival** here refers to the specific measurement of the number of live plants, usually 6-8 months old.

Responsibility for the experiment was taken over by the Forests Department (now CALM), when a tree research centre was set up in December 1984 at the Narrogin WADA.

A site was chosen on farmland 6 km west of Narrogin (Fig. 1) at the Narrogin Agricultural High School. The school is located on a working farm and provides Year 11 and 12 students with a vocational and academic agricultural education. The site had been used for pasture and crop production for a number of years. Original native vegetation was marri *(Eucalyptus calophylla)* and wandoo *(E. wandoo)* woodlands with pockets of brown mallet *(E. astringens)* on lateritic ridgetops. Soils were surveyed and found to be light grey loamy sands over coarser yellow sands, red mottles and medium clays and may be described as yellow podsolic (Stoneman 1991). Average annual rainfall for Narrogin is 500 mm, with most falling in winter months (Bureau of Meteorology 1965).

The aim of the experiment was to investigate factors affecting establishment of trees by direct seeding. The objectives of the experiment were:

- to assess the affect of sowing time on the germination and subsequent survival of seed sown of 12 tree species;
- to assess mechanical and chemical weed control methods on established pasture sites; and
- to assess the impact of seasonal variation between different years on time of sowing, weed control and tree species.

Methods

The direct seeding experiment established in 1984 was repeated at the high school site in 1985 and 1986, with treatments from the original experiment being used.

Treatments supporting the aims of the experiment were as follows.

Sowing time

Two sowing times (seasonal periods) were used for each of the three years of the experiment. The two seasonal periods were early (June-July) and late (August-September). Sowing dates were as follows:

early - 6 June 1984, 12 July 1985 and 21 July 1986;
late - 24 August 1984, 10 September 1985 and 8 September 1986.

Pre-sowing weed control

The choice of pre-sowing weed control treatments was based on those used in direct seeding experiments in South Australia by Copely and Venning (1983). The four pre-sowing weed control treatments tested in the experiment were as follows.

Scalping - approximately 10 cm of topsoil was removed by scalping with a road grader. Plots were then lightly scarified with tines to break up the soil surface one week before sowing. The aim of this treatment is to remove all weed material and soil-stored seed.

Paraquat-diquat - a broad spectrum, contact herbicide, *Spray-Seed*®[5] (125 g L^{-1} paraquat and 75 g L^{-1} diquat), was applied at a rate of 3 L ha^{-1} and one week later the site was lightly scarified and seeded. This treatment destroys surface weed material, but soil-stored seed and below-ground weed material remains undamaged.

Atrazine-amitrole - *Spray-Seed*® herbicide was applied at a rate of 3 L ha^{-1} two weeks before sowing and then plots were lightly scarified one week before sowing. *Vorox AA*® (a formulated contact-residual herbicide mix, 320 g L^{-1} atrazine and 320 g L^{-1} amitrole) was then applied to the plots at a rate of 4.37 L ha^{-1}. The treatment aims to control surface weed material with the contact component (atrazine) and soil-stored seed and below-ground weed material with the residual component (amitrole).

Atrazine - *Spray-Seed*® herbicide was applied two weeks before sowing at 3 L ha^{-1} and then the plots were scarified one week before sowing. *Flowable Gesaprim 500 FW*® liquid herbicide (500 g L^{-1} atrazine) was applied at 4.37 L ha^{-1} after this and the plots scarified again. This treatment was used only in 1985.

The purpose of the mechanical scalping treatment was to provide a control for comparison with the chemical treatments[6]. Chemical rates were based on previous experience elsewhere (Copley and Venning 1983; see also Venning and Croft 1985) and label recommendations for registered products[7].

Tree species

Twelve tree species commonly grown on farms and proven successful in direct seeding locally (T.Negus[8] personal communication) and elsewhere in Australia (Copley and Venning 1983; Venning 1985) were selected for the experiments. Local WA species included in the experiment were *Acacia acuminata, Allocasuarina huegeliana, Eucalyptus accedens, E. astringens, E. calophylla, E. loxophleba* and *E. wandoo.* Other species included natives from other parts of Australia - *E. camaldulensis, E. cladocalyx* var. *nana, E. leucoxylon* var. *rosea* and *E. platypus* var. *heterophylla* - and the exotic fodder tree, *Cytisus proliferus* (tagasaste).

Experimental design and analysis

Weed control treatments were orientated north-south, parallel to the eastern edge of the paddock, and ran the length of each years' sowings. Sowing time and species treatments were run east-west.

The 1984 weed control treatments were placed next to the eastern edge of the paddock (Appendix 1). Weed

[5] The use of trade names for agricultural chemicals does not imply their endorsement.
[6] Control does not necessarily imply no treatment but provides a standard procedure (Andrew 1984).
[7] Agricultural chemicals may only be used for the purpose that they were registered for in each State in Australia.
[8] Mr Tim Negus was OIC of the Narrogin office of the WADA when he established the trial in 1984.

control treatments in 1985 ran parallel to the 1984 treatments, but further into the paddock. Owing to limited space on the experimental site, 1986 treatments were sown in areas where the previous two years' sowings had failed and species were doubled up, i.e. sown in random pairs in six mixed species treatments. Therefore, for each year's planting weed control treatments were allocated as a split-plot design, with two sowing dates, twelve species and three replications (Appendix 1).

With the exception of treatments to be scalped, the area sown in 1986 was sprayed with *Roundup*® at 1.5 L ha^{-1} two weeks before sowing. Plots were then scarified to assist weed control and loosen soil before sowing. The 1986 experimental area was sprayed with an application of *Rogor 40*® to control red-legged earth mites one week before the late sowing treatments.

Each plot measured 17 m^2 (1.7 m x 10 m). Seed was dropped on the soil surface in plots through pipes attached to the tines of an experimental cone seeder. Each tine of the seeder was large enough to push surface soil without soil covering or compaction. Seeding rates were calculated to 2 kg ha^{-1} for all treatments.

Each species was sown separately without fertilizer or bulking agent. The hard-coated seeds of *Acacia acuminata* and *Cytisus proliferus* were mechanically scratched before sowing to help break seed dormancy. None of the other seed was pre-treated. Expected number of germinants for each species (in each seed lot) was provided by the CALM seed store, where laboratory testing was conducted.

Seedling survival is expressed either as numbers of germinating plants, or as a percentage of the numbers expected based on the amount of viable seeds sown. Pre-emergent losses were not practically quantifiable in these experiments. Therefore, seedling survival is the number of seed less losses from a number of causes such as seed and pre-emergent deaths[9].

Numbers of germinants were transformed with the formula $ln(x+1)$ prior to analysis, as counts of germinants were characteristically skewed (Snedecor and Cochran 1980). As the nature of treatments varied slightly from year to year, each year's experiment was analysed separately as split-split plots. Data were analysed by ANOVA using the SAS statistical package.

Results

Rates of germination varied between years for some species. Survival of germinated seed was found to be relatively small for each species in each year (Table 1). Optimum germination temperature for seed lots of each species was not recorded at the time of germination testing.

Analysis of variance (Table 2) indicated a number of significant interactive effects. In 1984, all treatment interactions were significant. In 1985 and 1986, the species x sowing time effect was significant[10].

The most important effect overall was time of sowing. This was determined by testing for additional, consistent differences between sowing times and between species[11]. Late sowings were largely unsuccessful; mean germinants of all species (1984-1986) for early sowing treatments = 7.2, 8.0, 18.6; late = 0.6, 0.1, 0.8.

This result held for the majority of species, with the exception of *Acacia acuminata* and *Eucalyptus calophylla*, which had low germination in both early and late sowings (Fig. 2).

As indicated by the relative magnitudes of the F statistic, differences between June and August sowings (1984) were not as pronounced as differences between July and September sowings in other years (Table 2).

This is supported by Narrogin's monthly rainfall data for the three years of the experiment (Fig. 3). Late sowings in 1985 and 1986 were followed by a relatively small amount of rain. Total annual rainfall for Narrogin was 462.0 mm, 435.0 mm, 387.2 mm (1984, 1985, 1986), all below the long-term annual average rainfall for Narrogin of 494.3 mm (Anon 1991).

In order to assess the relationship between species type and weed control on the survival of germinants, the early sowing data were further analysed. For early sowings, the only consistently significant effect was owing to species, partially confounded by weed treatment in 1984 (Fig. 4). The species and weed control main effects may be compared with their interaction as outlined above. Although species and weed control treatments did not produce a consistent germination response, apparently the method of weed control had a large effect on germination, and differences between species were pronounced in 1984, but not in 1985 and 1986 (Table 2).

Mean germination of species in each year indicated that greater numbers of *Eucalyptus wandoo* and *E. loxophleba* consistently germinated, although not as high as expected (Table 3). *E. cladocalyx, E. camaldulensis, E. astringens* and *E. platypus* also performed consistently well, and *Allocasuarina huegeliana* produced large numbers of germinants in 1986, but largely failed in 1984.

Weed control treatments produced different results for sowing times in 1984 (all species) and many species did not germinate consistently under different combinations of weed control and sowing time treatments (Table 4). Response patterns were inconsistent across the experiment, and it is difficult to draw precise conclusions about weed control from these results.

Weed control had a marked effect on germination in 1984, but marginal or nil effect in other years (Table 2). Examination of mean germinants for each weed control

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9 Survival of seedlings at 2-4 months was recorded for this and the other field experiments but is not presented here. The use of data collected post-summer would eliminate one of the many factors, summer drought, that reduce seedling survival. Summer drought is a probable cause of seedling death in south-west WA (Runciman personal communication).

10 In order to ensure an overall Type I error rate of 0.05, the per-comparison Type I error rate of 0.05 / 50 = 0.001.

11 To test whether or not there is a pattern of responses, the appropriate denominator MS (mean squares) for such a test is the pooled interaction MS (Cochran and Cox 1957). It should be noted that this method is approximate, and that resulting F values which are marginally significant should be treated with caution.

TABLE 1

Expected number of germinants, observed number of seedlings and percentage survival of 12 native tree species between 1984 - 1986, Narrogin Direct Seeding Experiment.

SPECIES NAME	YEAR OF SOWING	CALM SEED LOT CODE	EXPECTED NO. OF GERMINANTS	ACTUAL NO. SEEDLINGS X ± SE	SURVIVAL OF SEEDLINGS (%)
Eucalyptus accedens	1984	6274	422	2.22 ± 5.55	0.53
	1985	D159	292	3.04 ± 5.21	1.04
	1986	D121	323	5.61 ± 10.01	1.74
Acacia acuminata	1984	D347	267	0.39 ± 0.85	0.14
	1985	D629	173	0.29 ± 0.55	0.17
	1986	D629	173	1.39 ± 1.58	0.80
E. cladocalyx var. *nana*	1984	D296	67	1.05 ± 2.69	1.57
	1985	D675	334	6.38 ± 2.75	1.91
	1986	D675	334	15.67 ± 8.09	4.69
E. camaldulensis	1984	D288	921	5.33 ± 9.00	0.58
	1985	D288	959	5.42 ± 10.16	0.56
	1986	D918	1056	5.78 ± 10.93	0.55
E. leucoxylon var. *rosea*	1984	D247	272	2.39 ± 4.15	0.88
	1985	D247	284	1.50 ± 2.81	0.53
	1986	?D247	723	2.33 ± 3.45	0.32
Allocasuarina huegeliana	1984	D352	796	0.28 ± 1.18	0.04
	1985	D352	828	4.69 ± 14.60	0.57
	1986	D352	828	43.17 ± 75.79	5.21
E. wandoo	1984	D162	681	11.83 ± 25.80	1.74
	1985	D32	1042	6.13 ± 9.33	0.59
	1986	D14	334	14.50 ± 40.53	4.34
E. calophylla	1984	D369	24	0.89 ± 1.41	3.71
	1985	D587	67	1.08 ± 3.28	1.61
	1986	D890	42	0.61 ± 1.34	1.45
E. loxophleba	1984	D342	2430	12.17 ± 30.09	0.50
	1985	D50	2016	8.58 ± 10.77	0.43
	1986	D882	1774	13.67 ± 22.89	0.77
E. astringens	1984	D353	320	3.44 ± 9.73	1.08
	1985	D77	284	3.79 ± 5.73	1.33
	1986	D77	284	6.33 ± 12.43	2.23
E. platypus var. *heterophylla*	1984	7355	134	5.06 ± 14.86	3.78
	1985	8431	881	6.42 ± 9.71	0.73
	1986	?	?	4.83 ± 13.58	NA
Cytisus prolifera	1984	NA	NA	1.39 ± 2.33	NA
	1985	D71	167	1.67 ± 3.03	1.00
	1986	D349	187	2.89 ± 3.05	1.55

treatment over time suggested scalping was superior to other treatments, although not consistently so (Fig. 4).

Scalping was compared with other treatments in post-hoc contrasts (Table 4). Scalping gave significantly higher germination than other weed control treatments in 1984 and 1986 (Fig. 4). However, this result was reversed in 1985, when scalping resulted in significantly fewer germinants. This result may have been related to lower overall germination in 1985.

Remarkably, no block effects were significant despite the high degree of variability between years. Although results varied markedly over years and sowing times, there was no evidence of any spatial variability within the site.

Discussion

Results in this study showed marked variation from year to year. This highlights the difficulty in making clear recommendations for direct seeding, as results are not predictable and are highly variable between years. No treatment or species from our results consistently gave the best performance. This demonstrates the importance of studies replicated under a variety of conditions and over a number of years. Recommendations based only on a single year's data must be treated with great caution.

Despite variation in results, a number of factors of practical significance can be identified for predicting establishment success in direct seeding.

Sowing time was the most important factor influencing germination of species in these experiments. Availability of soil moisture after sowing is a critical factor in site rehabilitation by direct seeding of native trees (Venning 1988; Buchanan 1989; Buchhorn *et al.* 1989). In the mediterranean-type climate of the south-west of WA, most reliable rainfall occurs within the period late autumn to early spring. However, the distribution and quantity of rainfall varies each year and monthly rainfall may be highly variable from year to year. The average break of season for Narrogin is late April and the growing season lasts for an average of 5-6 months (Bureau of Meteorology 1965).

The lack of variability in experiments within years, in contrast to variability between years, suggests that annual climatic variation is a major determinant of germination success. Results given here indicate that early sowings (June-July) are most effective in direct seeding. However,

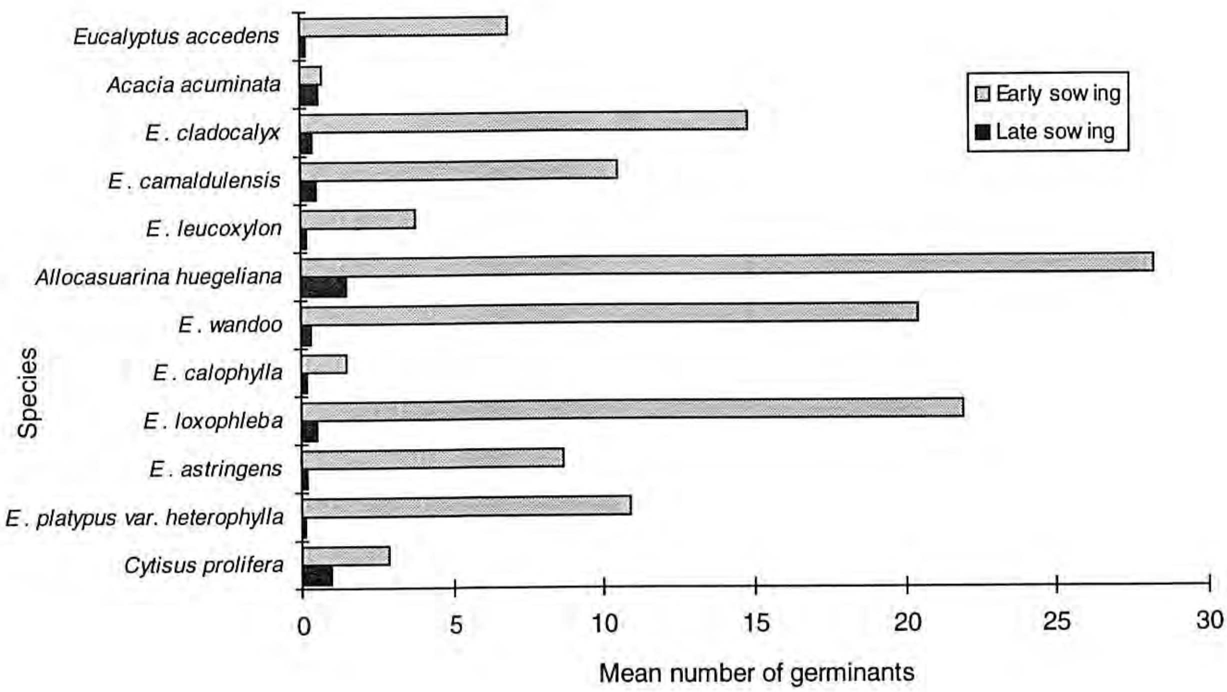

Figure 2. Mean germination at early (June-July) and late (August-September) sowings for tree species in the Narrogin Direct Seeding Experiment 1984-1986.

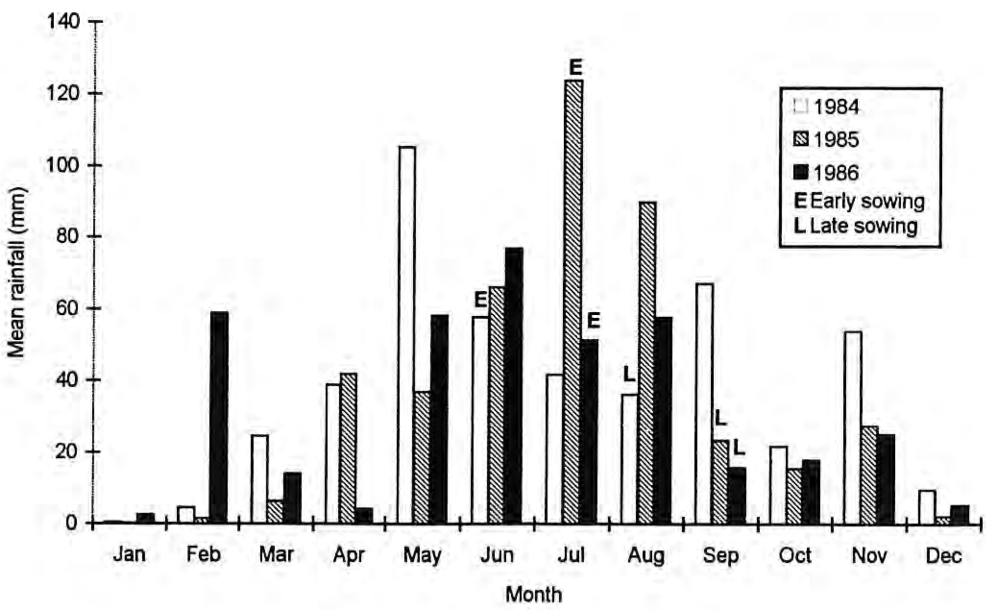

Figure 3. Monthly rainfall for Narrogin, WA 1984 - 1986.

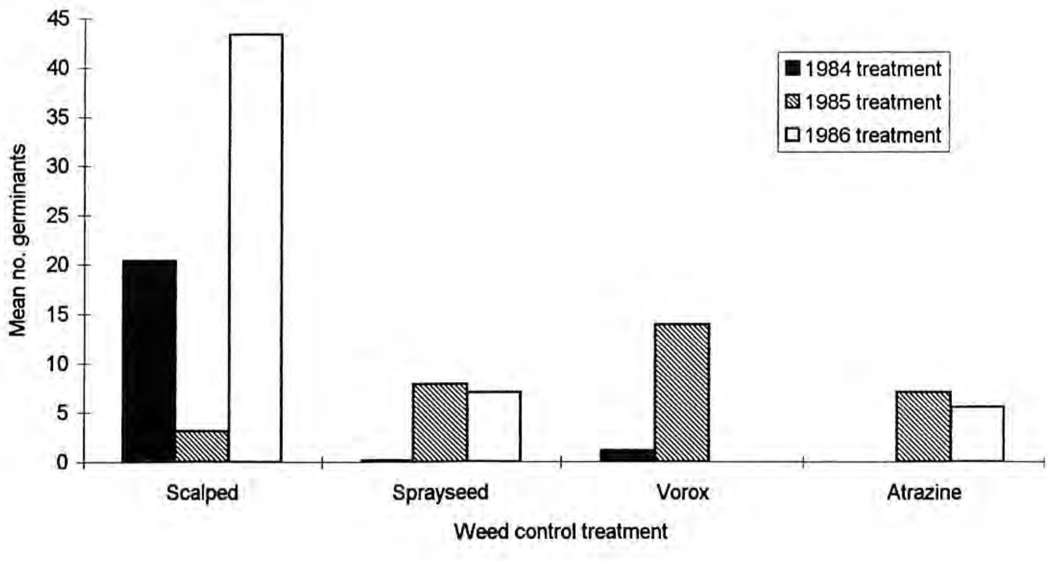

Figure 4. Mean number of germinants (early sowing) for each weed control treatment in 1984, 1985 and 1986 for the Narrogin Direct Seeding Experiment.

TABLE 2

Analysis of Variance, Narrogin Direct Seeding Experiment 1984-1986.

YEAR	1984			1985			1986		
Effects	DF	MS	F	DF	MS	F	DF	MS	F
Main Plots									
Block	2	0.7	2.6	2	3.5	2.0	2	0.8	0.2
Weed Control (W)	2	22.2	79.1***	3	6.9	4.1*	2	21.0	6.5
Error	4	0.5		6	1.7		4	3.2	
Sub-plots									
Sowing time (T)	1	121.4	43.8***	1	143.2	65.1***		1133.3	47.8***
T (pooled error)			9.8**			116.0***			60.5***
T x W	2	21.6	44.2***	3	8.5	3.9	2	12.2	4.4
Error	6	0.5		8	2.2		6	2.8	
Sub-sub-plots									
Species (S)	11	1.5	5.28***	11	3.2	8.0***	11	4.3	11.8***
S x W	22	1.5	5.27***	33	0.3	0.8	22	0.6	1.5
S x T	11	0.9	3.22***	11	2.2	5.5***	11	3.6	9.9***
S x T x W	22	1.0	3.74***	33	0.2	0.6	22	0.6	1.5
Error	132	0.3		176	0.4		132	0.4	
Pooled time of sowing interaction	35	2.2		47	1.2		35	2.2	

* $P < 0.001$
** $P < 0.0005$
*** $P < 0.0001$

TABLE 3

Mean number of germinants (early sowings) and percentage seedling survival, calculated from expected number of germinants, for each species for 1984, 1985 and 1986 in the Narrogin Direct Seeding Experiment.

SPECIES	YEAR					
	1984		1985		1986	
	mean no. germinants	seedling survival (%)	mean no. germinants	seedling survival (%)	mean no. germinants	seedling survival (%)
Eucalyptus accedens	3.8	0.90	6.0	2.05	11.2	3.43
Acacia acuminata	0.1	0.04	0.4	0.23	1.8	1.05
E. cladocalyx	1.7	2.54	12.8	3.83	30.6	9.16
E. camaldulensis	9.1	0.99	10.8	1.13	11.6	1.10
E. leucoxylon	4.0	1.47	3.0	1.06	4.7	0.65
Allocasuarina huegeliana	0.6	0.08	8.8	1.06	81.6	9.86
E. wandoo	23.0	3.38	11.9	1.14	29.0	8.68
E. calophylla	1.7	7.08	2.2	3.28	0.6	1.43
E. loxophleba	23.9	0.98	16.2	0.80	27.3	1.54
E. astringens	6.8	2.13	7.5	2.64	12.1	4.26
E. platypus	9.8	7.31	12.8	1.45	9.7	NA
Cytisus prolifera	1.7	1.02	3.3	1.98	3.7	1.98

TABLE 4

Analysis of Variance of number of germinants in 1984 Narrogin Direct Seeding Experiment, early sowings.

EFFECTS	DF	SS	MS	F
Main Plots				
Block	2	0.03	0.01	0.11
Weed Control(W)				
post-hoc contrast	2	81.12	40.56	317.56***
scalping v other	1	79.56	79.56	622.98***
Error	4	0.51	0.13	
Sub-plots				
Species(S)	11	23.06	2.10	4.89***
S x W	22	48.61	2.21	5.15***
Error	66	28.30	0.43	

* $P < 0.001$
** $P < 0.0005$
*** $P < 0.0001$

relative success varied between years, and may reflect the suitability of rainfall and temperature patterns within particular years. Temperature was not recorded during the experiment and may have influenced results. Reliability and seasonal pattern of annual rainfall, and maxima and minima temperatures have been recognized as factors affecting rehabilitation in the dryer parts of WA (Malcolm 1990).

Results from early sowing indicate that weed control has a large impact on germination. This supports research findings elsewhere (Bird *et al.* 1990; Panetta and Groves 1990). However, no one treatment gave reliable results in all three years of this study. Scalping appeared to be best, and was superior to other treatments in two of three years although it resulted in the fewest germinants in 1985 when overall germination was lowest. Higher than average rainfall after sowing in 1985 may have resulted in water-logging and reduced overall germination.

The three chemical weed control treatments comprised broad spectrum herbicides normally used before sowing for contact and residual activity. These are highly phytotoxic and when used for ground preparation, delay periods are advised before sowing (CALM 1988). Chemical toxicity from herbicides may therefore have resulted in some poor germination results. Similar weed control results were achieved for direct seeding experiments in South Australia (Panetta and Groves 1990), where atrazine-amitrole and scalping were found to improve establishment of large-seeded species. Poor establishment was recorded for small-seeded *Eucalyptus* and *Melaleuca* spp. across the South Australian experiments.

Although scalping was the best method for weed control in this experiment, tree performance measured in 1990 (unpublished data) was found to be greatly reduced compared with chemical treatments. Despite concerns about the safety of herbicides, this type of weed control is the most practical as many farmers use chemicals for crop and pasture establishment. A variety of work has been done recently to test the tolerance of native species to herbicides that control broadleaf weeds pre- and post-establishment (e.g. Pigott 1989; Bird *et al.* 1990; Webb 1991; Negus 1992). Broad-leaf herbicides from these later experiments are known to be superior to those used in this experiment.

Some broad-leaf herbicides and known 'safe' grass-control herbicides offer good post-emergent weed control options for direct seeding projects. However, these are expensive and reliance on them risks establishment failure from weed competition. Good site management and weed control prior to sowing are recommended to ensure maximum seedling establishment and survival rates.

For the species tested in this experiment, germination performance was not consistent across treatments within years, nor from year to year. However, some species rated well overall. *Eucalyptus wandoo* and *E. loxophleba* consistently germinated best. *E. cladocalyx*, *E. camaldulensis, E. astringens* and *E. platypus* also performed consistently well. *Allocasuarina huegeliana* produced large numbers of germinants, but only in one year. These results indicate likely species for inclusion in direct seeding work. These species should also be included for comparison in any future direct seeding experiments in WA. The larger-seeded native species, *Cytisus proliferus, Acacia acuminata* and *Eucalyptus calophylla* produced low numbers of germinants or were unreliable. Depth of sowing and seed dormancy may be important factors in interpreting the failure of these species as all seed was surface sown. Deep sowing (5-10 mm) has been shown to significantly improve germination of these large-seeded species.

In the experiment, several factors interacted, and no consistent results are evident. Results show that the interaction of weed control, sowing time and species suitability are likely to contribute to relative germination success in direct seeding. This concurs with a review of direct seeding research in South Australia (Dalton 1990) and recent direct seeding experiments conducted in Victoria (Bird *et al.* 1990).

BROADSCALE DIRECT SEEDING TECHNIQUES EXPERIMENT

Background

Despite great potential for rapid, cost-effective regeneration of WA farmland, direct seeding was not widely embraced in the mid 1980s. This was owing in part to a high failure rate by early practitioners, leading to a perception by farmers that other methods of revegetation were more reliable.

Factors known to affect the establishment of direct-seeded native trees on pasture are effective weed control, sowing time and the sowing of adequate germinable seed (Copley and Venning 1983; Edmiston 1985).

An experiment was established to research factors affecting establishment of direct-seeded native trees under local conditions.

The aims of the experiment were:

- to assess mechanical and chemical weed control methods on established pasture sites at a number of different wheatbelt locations;
- to compare germination and subsequent survival of seed sown for a number of Australian native species at different sowing times; and
- to determine whether survival is improved by compacting the soil surface directly after seed is sown.

Methods

Four sites were chosen: two at Badgingarra and one each at Shackleton and Jerramungup (Fig. 1). This enabled comparison of regional differences within the wheatbelt. One of the Badgingarra sites (Badgingarra P) and both the Shackleton and Jerramungup sites were on established pasture while the second Badgingarra site (Badgingarra NL) was on recently-cleared land.

The recently-cleared site was included to provide a control for the established pasture sites, soils of which are known to have become degraded by agriculture. At each site, treatments were arranged factorially in split-plots. Plots were blocked to account for differing soil types: sand and duplex (sand over gravel) at the Badgingarra sites and clay and duplex (loam over clay) at the other sites. Four treatments were incorporated at each site as follows.

Weed Control

Up to seven weed control treatments, including chemical and mechanical combinations, were applied at some sites[12]. To allow reliable comparison only treatments consistent to all sites were analysed. They were:

Scalping: topsoil was scalped to a depth of 10 cm and removed from plots;
Paraquat-diquat *(Sprayseed®)* was sprayed at a rate of 3 L ha^{-1} and soil scarified to 100 mm one week after spraying;
Scarify and atrazine-amitrole *(Vorox AA®)*: soil was scarified to 100 mm and sprayed with atrazine-amitrole at a rate of 4 L ha^{-1}.

Sowing times

Three sowing times, representing winter or the period of major rainfall, were used in the experiment:

early - May 1986;
middle - July 1986;
late- August 1986.

For practical reasons sowing times varied within one week between some sites because of the locations (Fig. 1).

Compaction

Two treatments were applied:

no compaction;
compaction by tractor wheel.

Seeds were hand-sown and superphosphate (1-2 kg per plot) used as a bulking agent. Each treatment plot was split, and one-half compacted using a tractor immediately after sowing.

Tree species

Nine tree species were tested in the experiment, namely: *Acacia acuminata, Allocasuarina huegeliana, Eucalyptus accedens, E. calophylla, E. camaldulensis, E. gomphocephala, E. loxophleba, E. todtiana* and *E. wandoo*. All species are native to south-west WA except for *E. camaldulensis* which is broadly distributed along river courses in south-eastern and inland Australia (Boland *et al.* 1984).

[12] Weed control treatments not analysed here included scarify twice, paraquat-diquat and triple disc seeder, atrazine-amitrol and triple disc seeder, furrowline only and furrowline and atrazine-amitrol.

Results

Seedling survival was low for all species (Table 5) but comparable with results from the Narrogin Direct Seeding Experiment (Table 1). Survival means were similar for all species except *Allocasuarina huegeliana*, which was ten times higher than the lowest mean, *Acacia acuminata*, and 3.6 times higher than the second highest mean, *Eucalyptus gomphocephala*. Actual number of germinants was highest for *Allocasuarina huegeliana* and percentage seedling survival highest for the two large-seeded eucalypts, *E. calophylla* and *E. todtiana* (Table 5).

Analysis of variance for individual sites indicated a number of significant interactive effects, demonstrating inconsistencies in response of all species to weed control and sowing time treatments (Table 6). Only the species x weed control, time of sowing x species, time of sowing x weed control and time of sowing x weed control x compaction interactions are consistently significant or likely to be of practical importance. Without any other consistent evidence of a significant compaction effect, the second order interaction is discounted. Evaluation of the compaction main effect was deferred until analysis of the pooled sites' data, because of insufficient degrees of freedom for error. Clearly, other main effects had a significant impact on germination although the magnitude of these effects varied considerably between sites.

Overall significance of the interactions and main effects was estimated from a pooled analysis of all sites (Table 7). Weed control, sowing time and species were important factors in germination success, and all were involved in significant interactions with sites. These interactions form the basis of separate treatment analyses.

Best overall germination response to time of sowing was the middle sowing (July). This was 1.2 and 1.6 times higher than the combined early and late sowings for the Badgingarra NL and Shackleton sites respectively (Fig. 5). A marginally better response for early than late sowing was recorded at Jerramungup, and higher germination was achieved by the late sowing than the combined early and middle sowing at the Badgingarra P site.

Scalping provided consistently better germination rates than the other two weed control treatments (Fig. 6). Increased germination response varied between 1.25 times the overall average at the Badgingarra NL site to seven times at Jerramungup. Clear differences existed between sites, with markedly greater overall germination at the Badgingarra NL site.

Species response varied between sites, although some species performed consistently. Best results for all species were recorded at the Badgingarra NL site which had greater numbers of germinants than the combined number of germinants at the other sites. *Allocasuarina huegeliana* performed best, producing almost four times as many germinants as *Eucalyptus gomphocephala*, which was the next best species. *E. loxophleba, E. calophylla, E. gomphocephala* and *A. huegeliana* gave relatively consistent germination rates across sites (Table 8). *E. todtiana* performed relatively well at the Badgingarra NL site but relatively poorly at the other sites. *E. wandoo*, although best performer at Jerramungup, performed

TABLE 5

Expected number of germinants, actual number of seedlings and percentage seedling survival with rank in parentheses for species used in Broadscale Direct Seeding Techniques Experiment.

SPECIES NAME	CALM SEED LOT CODE	EXPECTED NO. OF GERMINANTS	ACTUAL SEEDING NO. X ± SE	SEEDLING SURVIVAL (%)
Eucalyptus accedens	D 48	112 *(5)*	0.64 *(8)*	0.57 *(5)*
Acacia acuminata	6809	80 *(7)*	0.38 *(9)*	0.48 *(7)*
E. todtiana	D776	45 *(8)*	0.75 *(6)*	1.67 *(3)*
E. camaldulensis	D249	158 *(3)*	0.72 *(7)*	0.46 *(8)*
E. gomphocephala	D384	190 *(2)*	1.06 *(2)*	0.56 *(6)*
Allocasuarina huegeliana	D352	149 (4)	3.82 *(1)*	2.56 *(2)*
E. wandoo [a]	7322	86 *(6)*	0.83 *(5)*	0.96 *(4)*
E. calophylla	D890	25 *(9)*	0.94 *(4)*	3.76 *(1)*
E. loxophleba	D342	607 *(1)*	0.97 *(3)*	0.16 *(9)*

[a] this seed was collected in 1984 as inland wandoo, and is likely to be *E. capillosa* ssp. *capillosa* (Brooker and Hopper 1991).

TABLE 6

ANOVA of transformed germinants at four sites for Broadscale Direct Seeding Techniques Experiment.

SITE		JERRAMUNGUP		BADGINGARRA-NL		BADGINGARRA-P		SHACKLETON	
	DF	MS	F	MS	F	MS	F	MS	F
Main Plots									
Block	1	0.27	1.26	4.58	757.51*	0.72	0.62	2.64	8.67
Compaction (C)	1	0.01	0.07	0.00	0.32	0.18	0.16	0.16	0.52
Error	1	0.21		0.01		1.16		0.30	
Sub-plots									
Species (S)	8	0.53	3.59***	6.77	21.36**	1.51	7.78***	0.84	7.36***
S x C	8	0.09	0.63	0.26	0.83	0.04	0.21	0.08	0.71
Weed control (W)	2	13.28	89.71***	2.99	9.44***	5.68	29.25***	1.25	10.98***
W x C	2	0.03	0.22	5.19	16.37***	0.25	1.28	0.30	2.64
S x W	16	0.52	3.50***	0.81	2.55**	0.39	2.02*	0.20	1.79*
S x W x C	16	0.09	0.59	0.22	0.70	0.09	0.45	0.10	0.85
Sowing time (T)	2	0.37	2.53	21.95	69.31***	2.42	12.44***	3.29	28.84***
S x T	16	0.13	0.90	1.17	3.71***	0.59	3.06***	0.20	1.74*
T x W	4	0.34	2.30	1.74	5.51***	0.97	4.97***	1.19	10.46***
T x W x C	4	0.51	3.42**	2.14	6.76***	0.68	3.48**	0.30	2.65*
S x T x C	16	0.08	0.51	0.39	1.23	0.13	0.67	0.12	1.05
S x T x W	32	0.13	0.91	0.44	1.40	0.19	0.98	0.17	1.50
S x T x C x W	32	0.08	0.57	0.29	0.92	0.23	1.20	0.12	1.03
Error	160		0.15		0.32		0.19		0.11

* $P < 0.001$
** $P < 0.0005$
*** $P < 0.0001$

TABLE 7

ANOVA of site by treatments for Broadscale Direct Seeding Techniques Experiment.

STATISTIC	DF	SS	MS	F
Main Plots				
Locality (L)	3	97.79	32.60	15.90
Block	4	8.20	2.05	4.88
Compaction (C)	1	0.14	0.14	0.34
L x C	3	0.22	0.07	0.17
Error	4	1.68	0.42	
Sub-plots				
Time (T)	2	20.52	10.26	1.73
L x T	6	35.55	5.92	24.07***
Weed Control (W)	2	22.81	2.90	2.90
L x W	6	23.60	3.93	15.98***
Species (S)	8	24.72	3.09	1.41
L x S	24	52.48	2.19	8.89***
T x S	16	9.75	0.61	2.48**
W x S	16	13.86	0.87	3.52***
Error	1200	295.32	0.25	

* $P < 0.001$
** $P < 0.0005$
*** $P < 0.0001$

relatively poorly at the other sites (Table 8). *Acacia acuminata* germinated at consistently low rates at all sites and rates were the lowest of all species.

All species except *A. acuminata* and *E. calophylla* germinated best for the July sowings (Table 9). Results for each species were influenced by the high number of germinants recorded at the Badgingarra NL site where sowing time differences were distinct. Similarly, all species except *A. acuminata* showed best response to scalping (Table 10). Scalping produced a gain of 2.5 times relative to the combined herbicide treatments.

Discussion

Variability between and within sites was high, and none of the sowing time, species or soil preparation treatments produced consistently or significantly improved establishment. However, each is of practical importance in increasing the level of germination. More germinants were recorded at the Badgingarra NL site, representing the only plots not located on old agricultural land. This may reflect better soil structure of newly cleared sand-plain sites (Grewer 1988) and the presence of mycorrhiza and appropriate nutrients.

With the exception of marginal differences at the Badgingarra P site, failure of the late sowings concurs with the results of the Narrogin Direct Seeding Experiment, where late sowings consistently failed over three years. Middle (July) sowings favoured all except the two large-seeded species *A.acuminata* and *E.calophylla*. These species were probably disfavoured by the hand sowing technique and may require sowing deeper than 5 mm (refer to section Effects of Soil Depth on Seed Germination Experiment). The difficulty of using large-seeded or hard-seeded species in this experiment is contrary to results of direct seeding experiments in South Australia (Panetta and Groves 1990).

Poor weed control, particularly ryegrass *(Lolium rigidum)* and capeweed *(Arctotheca calendula)*, at the pasture sites (unpublished data) and low seeding rates at all sites are most likely reasons for low rates of establishment in the experiment. Despite poor weed control, scalping provided the relatively best weed control, although this treatment has been observed to affect long-term performance (see discussion in section Narrogin Direct Seeding Experiment). Herbicide treatments had a detrimental effect on the overall results for most species. This was not unexpected as both chemicals used are broad spectrum herbicides (Swarbrick 1984). Paraquat-diquat at the Badgingarra NL site and atrazine-amitrole at the Shackleton site provided results comparable to those of scalping at the respective sites.

For the limited number of species which performed well in this study, scalping and atrazine-amitrol could be combined to produce significant increases in germination levels. Other herbicides now available may provide better pre-sowing weed control for direct seeding (refer to section Narrogin Direct Seeding Experiment).

TABLE 8

Mean number of germinants, with rank in parentheses, at different sites for Broadscale Direct Seeding Techniques Experiment.

SPECIES NAME	SITE			
	JERRAMUNGUP	BADGINGARRA-NL	BADGINGARRA-P	SHACKLETON
Eucalyptus accedens	0.78 (3)	1.19 (8)	0.14 (7)	0.44 (4)
Acacia acuminata	0.08 (9)	0.72 (9)	0.67 (2)	0.06 (9)
E. todtiana	0.14 (7)	2.50 (3)	0.11 (8)	0.25 (5)
E. camaldulensis	0.11 (8)	2.25 (4)	0.28 (6)	0.25 (5)
E. gomphocephala	0.61 (4)	2.75 (2)	0.03 (9)	0.86 (2)
Allocasuarina huegeliana	0.44 (5)	11.22 (1)	3.47 (1)	0.14 (7)
E. wandoo[a]	1.08 (1)	1.50 (7)	0.58 (5)	0.14 (7)
E. calophylla	0.28 (6)	1.89 (5)	0.67 (2)	0.92 (1)
E. loxophleba	0.89 (2)	1.67 (6)	0.61 (4)	0.72 (3)

[a] this seed was collected in 1984 as inland wandoo, and is likely to be *E.capillosa* ssp. *capillosa* (Brooker and Hopper 1991).

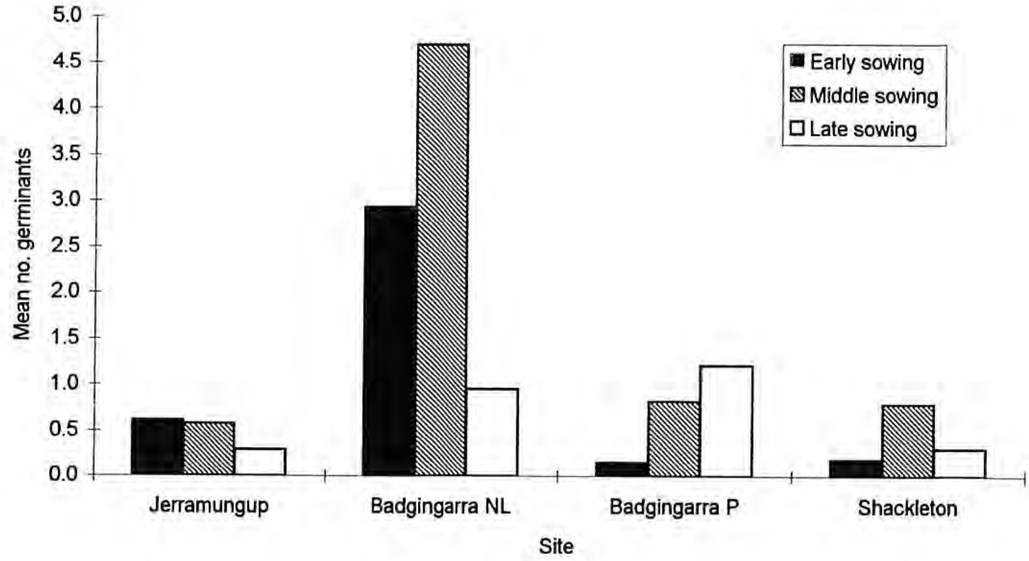

Figure 5. Mean number of germinants (all species) for time of sowing at four wheatbelt sites for the Broadscale Direct Seeding Techniques Experiment.

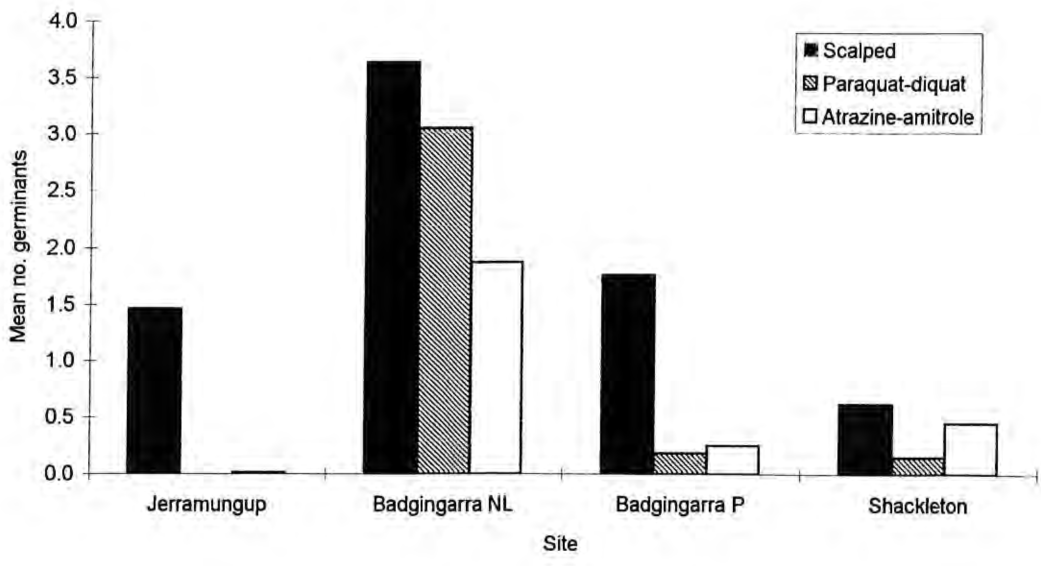

Figure 6. Mean germinants for weed control treatments at four wheatbelt sites for the Broadscale Direct Seeding Techniques Experiment.

TABLE 9

Response of species at different sowing times, with rank in parentheses, for Broadscale Direct Seeding Techniques Experiment.

SPECIES NAME	SOWING TIME		
	June	July	August
Eucalyptus accedens	0.48 (8)	1.19 (4)	0.25 (8)
Acacia acuminata	0.15 (9)	0.48 (9)	0.52 (4)
E. todtiana	0.88 (4)	1.15 (6)	0.23 (9)
E. camaldulensis	0.56 (7)	1.19 (4)	0.42 (6)
E. gomphocephala	0.98 (3)	1.92 (2)	0.29 (7)
Allocasuarina huegeliana	3.00 (1)	5.85 (1)	2.60 (1)
E. wandoo [a]	0.85 (5)	0.98 (7)	0.65 (3)
E. calophylla	1.15 (2)	0.92 (8)	0.75 (2)
E. loxophleba	0.65 (6)	1.79 (3)	0.48 (5)
All species	0.97 (2)	1.72 (1)	0.69 (3)

[a] this seed was collected in 1984 as inland wandoo, and is likely to be *E.capillosa* ssp. *capillosa* (Brooker and Hopper 1991).

TABLE 10

Response of species to weed control treatments, with rank in parentheses, for Broadscale Direct Seeding Techniques.

SPECIES NAME	WEED CONTROL		
	Scalping	Paraquat-Diquat	Atrazine-Amitrole
Eucalyptus accedens	1.35 (5)	0.21 (9)	0.35 (8)
Acacia acuminata	0.42 (9)	0.23 (8)	0.50 (5)
E. todtiana	0.83 (8)	0.58 (5)	0.83 (3)
E. camaldulensis	1.17 (7)	0.58 (5)	0.42 (6)
E. gomphocephala	1.25 (6)	0.83 (2)	1.10 (2)
Allocasuarina huegeliana	6.65 (1)	3.40 (1)	1.42 (1)
E. wandoo [a]	1.60 (3)	0.65 (4)	0.23 (9)
E. calophylla	1.44 (4)	0.71 (3)	0.67 (4)
E. loxophleba	2.12 (2)	0.42 (7)	0.38 (7)
All species	1.87 (1)	0.84 (2)	0.66 (3)

[a] this seed was collected in 1984 as inland wandoo, and is likely to be *E.capillosa* ssp. *capillosa* (Brooker and Hopper 1991).

With the exception of a minor interaction with sowing time and weed control, post-sowing compaction was shown to have little affect on tree establishment at the four sites. However, this treatment should still be considered as it has been shown to improve establishment elsewhere (Runciman personal communication).

OPTIMUM SOWING TECHNIQUES EXPERIMENT

Background

On the basis of the experiments already described, this experiment was established to test the effects of ripping, sowing depth and sowing time on direct seeding results.

The aims of the experiment were:

- to determine whether *Acacia* and *Eucalyptus* establishment is improved by deep ripping;
- to determine whether *Acacia* and *Eucalyptus* establishment is improved by post-sowing harrowing and deep sowing, when compared with current surface sowing techniques;
- to compare autumn and winter sowing times for direct seeding native tree species.

The experiment was located on private property 12 km east of Narrogin on low-lying waterlogged, moderately saline and predominantly clay soils, (unpublished data). The site had been under crop and pasture rotation for several decades at the establishment of the experiment, but had begun to deteriorate owing to environmental factors mentioned above. Rainfall conditions are similar to the site of the Narrogin Direct Seeding Experiment located 20 km to the west.

Methods

Based on experience with previous experiments, a range of treatments were devised to test the effects of ripping, sowing method, sowing time, mixes of different tree seed and various combinations of these.

Ripping of soil to various depths ranging between 0.25 m and 0.75 m, is widely used for preparing sites for tree planting in the wheatbelt. Ripping breaks up soils compacted from agricultural practice to allow root penetration as the trees establish.

Farmers use a variety of methods to sow trees, dependent usually on suitable equipment available.

Sowing time has been shown to be crucial in the other experiments in determining the success of direct seeding, and three seasonal times were chosen for the experiment, early, middle and late.

As individual species are known to respond differently to direct seeding, four seed mixes comprising different species were devised.

The specific treatments were as follows.

Ripping

plots were ripped to a depth of 0.75 m on a 0.5 m spacing using a grader-mounted tine-ripper.
plots unripped.

Sowing method

surface sowing (control) through the cone seeder;
chain: seed was sown on the surface through the cone seeder and lightly covered by following with a 1.2 cm chain;
harrows: seed was sown on the surface through the cone seeder and covered by following with a set of finger harrows;
deep sowing: seed was sown 2-4 cm below the surface straight through the boots of the cone seeder and covered by following with a set of finger harrows.

Sowing time

early - 5 May;
mid - 5 June; and
late - 6 July 1987.

Species mix

Four mixes of *Eucalyptus* and *Acacia* spp. with one mix including *Allocasuarina huegeliana* were made up as follows.

mix 1: *Eucalyptus wandoo* and *Acacia saligna*;
mix 2: *Eucalyptus rudis, E. calophylla, Acacia microbotrya;*
mix 3: *Eucalyptus erythrocorys, E. camaldulensis, Acacia acuminata;* and
mix 4: *Eucalyptus loxophleba, Acacia pulchella, Allocasuarina huegeliana.*

Seed for the experiment was obtained from the CALM Seed Store where seeds of *Acacia* spp. were mechanically scarified. Seeds of other species were not treated before sowing. Seed was sown through the cone seeder over a distance of 15 m at a rate of 0.64 g of seed for small-seeded species and 1.28 g for larger-seeded species: the equivalent of 250 g ha^{-1} and 500 g ha^{-1} respectively.

Before ground preparation, oat stubble on the site was burnt in April 1987. Residual soil-stored weed seed was removed by grading off the top 5-10 cm of topsoil with a road grader. Experimental plots of sowing methods were established end-to-end across the site and one-half of each plot ground-ripped.

Treatments were arranged in a randomized factorial design, with four seed mixes x sowing time superimposed as a split plot. Plots were scarified immediately before sowing. Buffers of 2.5 m were included between plots and direct sown with leftover seed for protection against insect pests.

Seedlings were counted in January 1988, representing over-summer seedling survival approximately seven months after sowing in 1987. Seedling counts were transformed to $ln(x+1)$ prior to analysis to normalize the data (Snedecor and Cochran 1980.). Seedlings were again counted in December 1990 (i.e. at 42 months). However, these data were used only for basic summary statistics.

Results

Lower than expected numbers of seedlings were recorded for most species (Table 11).

Acceptable numbers of *A. saligna, A. microbotrya* and *Allocasuarina huegeliana* seedlings were established across all treatments. Analysis of variance of establishment after seven months indicated two major results (Table 12). First, differences between species accounted for most variation in germination. Second, applied treatments had little impact on overall establishment.

Not having a significant main effect for ripping, we discounted the significant interaction between this effect and other soil preparation treatments. Interaction between soil preparation treatment and species revealed a number of relevant factors (Table 12).

Eucalyptus rudis, E. erythrocorys and *E. camaldulensis* produced too few seedlings to indicate likely effects of soil preparation (Table 13). *Allocasuarina huegeliana* produced fewer, while *E. saligna, E. microbotrya, A. acuminata* and *A. pulchella* produced greater numbers of seedlings following deep sowing. Results for *E. loxophleba* and *E. wandoo* are unclear.

This differing pattern of response between species precludes assessment of treatment, main effects; clearly, recommendations can only be made concerning appropriate soil preparation treatments for a particular species.

There were noticeable differences between sowing times, but these were significant only as treatment interactions (Table 12). The number of seedlings recorded for *Acacia* spp. after seven months was expressed as a percentage of expected number of seedlings for each sowing time (Fig. 7).

The difference in establishment between seven and 42 months also varied between species (Fig. 8).

Allocasuarina huegeliana and *Acacia acuminata* had the highest levels of establishment between seven and 42 months with increases in numbers of seedlings to 164 per cent and 139 per cent respectively. *Eucalyptus erythrocorys* had no survivors and *Acacia pulchella* declined in numbers (34 per cent) for the same period (Fig. 8). Relative to actual numbers of seedlings, marginal changes in establishment were recorded for other species in the experiment between seven and 42 months (Table 11).

Discussion

The highest numbers of seedlings recorded across all treatments were for *Allocasuarina huegeliana* and *Acacia saligna*, although results for the former species were highly variable. Following July sowings, *Acacia microbotrya* and *A. saligna* out-performed other species in the experiment. July sowing produced higher numbers of seedlings for *A. acuminata*.

Acacia spp. out-performed *Eucalyptus* spp. in all seed mixes. Near failure for most *Eucalyptus* spp. may be attributable to poor tolerance of water-logging and marginally saline conditions at this site (S.Vlahos[13] personal communication). Despite lack of replication at other sites, these results indicate strong performance of *A. microbotrya* and *A. acuminata* under these site conditions.

Results for these two *Acacia* species went against the trend of other experiments, where *Acacia* spp. failed or were unreliable (see Narrogin Direct Seeding Experiment and Broadscale Direct Seeding Techniques Experiment). Marked decline in *A. pulchella* seedling survival may be attributed to known soil preferences and short life-span of this species (Monk *et al.* 1981).

Additional recruitment of *Allocasuarina huegeliana, Acacia acuminata* and *Eucalyptus loxophleba* was observed between seven and 42 months. This indicated that the dormancy of some seed was broken after one season in the soil.

Overall performance at this site was poor for all species except *Acacia microbotrya, A. saligna* and *Allocasuarina huegeliana.* The latter species performed much better than large-seeded species in previous experiments. Site factors are the most likely reason for this. Response to soil preparation treatments was variable and appears to be species specific. Deep sowing favoured *Acacia* spp., but disfavoured or was neutral to other species considered here. No marked differences were apparent between surface soil treatments except when combined with time of sowing or species.

As expected, ripping produced no significant gain in germination or survival rates, although the purpose of the treatment is to break up the subsoils of the planting area to allow root penetration. Differences in tree height or biomass may have been evident had they been measured after 42 months.

EFFECTS OF SOIL DEPTH ON SEED GERMINATION EXPERIMENT

Background

Hard-coated seeds of *Acacia* spp. are relatively large compared with other species. Seeds of *Acacia* spp. and other legumes have a dormancy period and require conditions of optimum moisture for germination (Richards and Beardsell 1987). Burial of seed at some depth in soil may provide these conditions. Previous experimental work

[13] Mr Steven Vlahos is a Research Officer based at the Katanning office of the WADA and conducts research into the establishment of saltbush (*Atriplex* spp.)and bluebush (*Maireana* spp.) in waterlogged and saline soils.

TABLE 11

Expected[a] and actual numbers[b] of seedlings and percentage survival at seven and 42 months of 11 species of native trees in the Optimum Techniques Experiment.

MIX	SPECIES NAME	LEVELS OF ESTABLISHMENT PER PLOT					
		amount of seed sown (g)	no.expected seedlings g^{-1} seed sown	no. seedlings expected	no. at 7 months X ± SE	% survival germinants seed at 6 months	no. at 42 months X ± SE
1	*Eucalyptus wandoo*	0.64	120	76.8	1.25±1.6	1.6	0.79±1.1
	Acacia saligna	1.28	38	48.6	8.92±6.2	18.3	8.88±6.8
2	*E. rudis*	0.64	292	186.9	0.04±0.2	0.02	0.04±0.2
	E. calophylla	1.28	7	9.0	1.04±1.2	16.2	0.54±0.8
	A. microbotrya	1.28	22	28.2	4.50±4.3	16.0	4.83±4.7
3	*E. erythrocorys*	1.28	11	14.1	0.08±0.4	0.6	0.00±0.0
	E. camaldulensis	1.28	47	60.2	0.04±0.2	0.07	0.04±0.2
	A. acuminata	0.64	158	101.1	3.38±3.1	3.3	4.71±4.8
4	*E. loxophleba*	0.64	910	582.4	1.92±4.1	0.3	2.42±4.6
	A. pulchella	1.28	104	133.1	3.92±3.3	2.9	1.42±1.8
	Allocasuarina huegeliana	0.64	298	190.7	10.96±10.7	5.8	17.96±15.7

[a] calculated from viability data supplied with seed
[b] only actual numbers of seedlings for 42 months

TABLE 12

Analysis of variance of germination for the three treatments after seven months in the Optimum Sowing Techniques Experiment.

SOURCE	DF	SS	MS	F
Main plots				
Ripping (R)	1	0.02	0.02	0.04
Sowing time (T)	2	2.67	1.34	2.02
Species (S)	10	141.01	14.10	21.29***
Pooled error	52	34.45	0.66	
Sub-plots				
Weed control (W)	3	1.85	0.62	2.49
R x W	3	2.33	0.78	3.13*
T x W	6	7.13	1.19	4.80***
W x S	30	23.49	0.78	3.16***
Pooled error	156	38.66	0.25	

* $P < 0.001$
** $P < 0.0005$
*** $P < 0.0001$

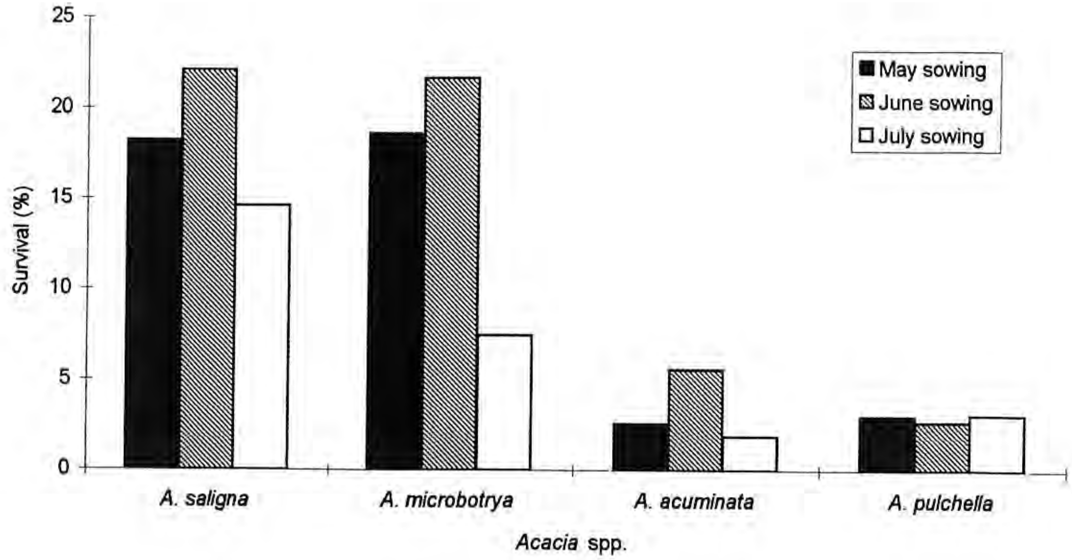

Figure 7. Level of survival at seven months (seedlings as a percentage of expected numbers) of four Acacia species for sowing time in the Optimum Sowing Techniques Experiment.

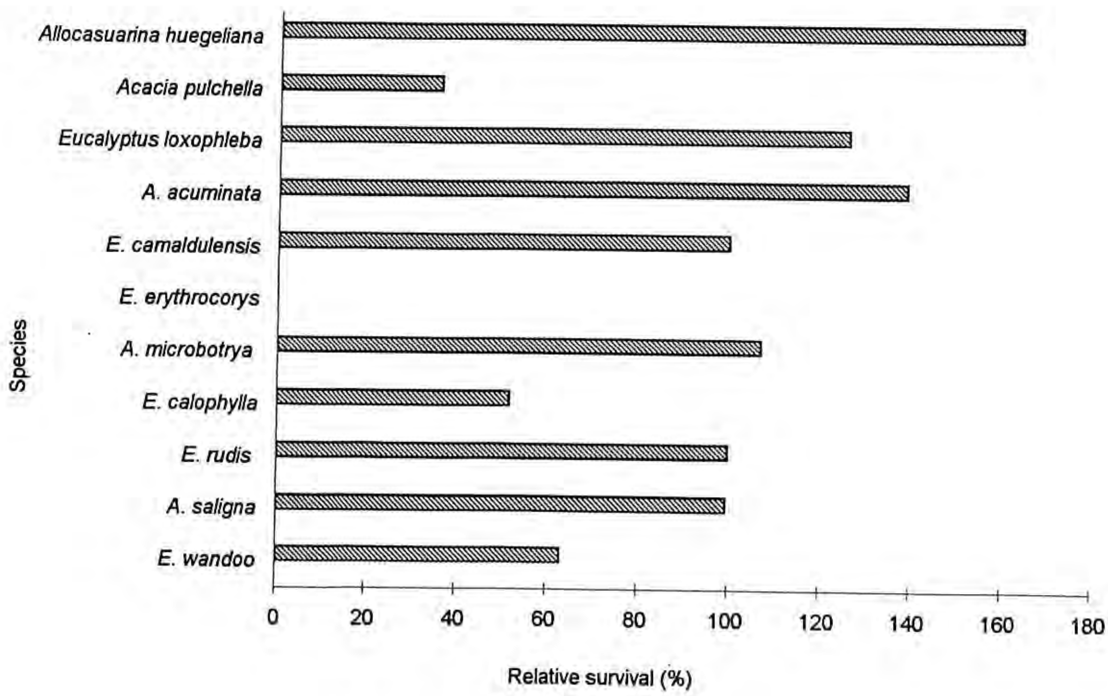

Figure 8. Ratio of survival at 42 months, as a percentage of survival after seven months, for species in the Optimum Sowing Techniques Experiment.

TABLE 13
Mean numbers of germinants for soil preparation treatments for species in the Optimum Sowing Techniques Experiment.

SPECIES NAME	TREATMENTS				
	SURFACE SOWN	HARROW	CHAIN	DEEP SOWN	MEAN
Eucalyptus wandoo	1.67	1.00	2.00	0.33	1.25
E. saligna	3.83	6.33	10.50	15.00	8.92
E. rudis	0.17	0.00	0.00	0.00	0.04
E. calophylla	0.33	1.00	2.00	0.83	1.04
E. microbotrya	1.50	4.50	4.00	8.00	4.50
E. erythrocorys	0.00	0.00	0.00	0.33	0.08
E. camaldulensis	0.17	0.00	0.00	0.00	0.05
Acacia acuminata	1.83	2.17	4.50	5.00	3.37
E. loxophleba	3.17	0.67	2.83	1.00	1.92
A. pulchella	4.00	2.67	3.00	6.00	3.92
Allocasuarina huegeliana	18.50	9.17	11.83	4.33	10.96
Species mean	3.20	2.50	3.70	3.71	-

(unpublished data) has revealed that small-seeded Myrtaceous species (e.g. *Eucalyptus*) germinate best when sown on the soil surface. Species (except *Allocasuarina huegeliana*) were selected to represent various seed sizes of *Eucalyptus* and *Acacia*.

An experiment was established to determine whether germination of *Acacia* and *Eucalyptus* seed is affected by depth of sowing in soil.

Methods

A fully randomized design was used with two species mixes, three treatments and two replications.

Species groups were (1) *Eucalyptus calophylla, E. camaldulensis, E. erythrocorys, E. loxophleba* and (2) *Acacia acuminata, A. dealbata, A. helmsii, A. microbotrya* and *Allocasuarina huegeliana*. Species chosen were representative of the range of seed sizes commonly found in these genera. Large-seeded species are those weighing more than one gram (Panetta and Groves 1990). *Acacia* seed was mechanically scarified prior to sowing. Forty seeds of each species were hand sown onto sterilized nursery soil (ratio 4:3 mix of crushed pine bark to sand plus added nutrients) in 5 cm deep, 30 x 35 cm plastic trays on 24 November 1986. The seed was then covered with soil to the prescribed depth. Sowing depth treatments were devised to reflect sowing practices in the field.

Sowing depth treatments were:

surface: seed placed on the surface with no soil covering;

light covering of soil: between 2 and 5 mm of soil to just cover seed; and

heavy covering of soil: between 5 and 10 mm of soil.

Trays were placed under 70 per cent shade cloth in the CALM nursery at Narrogin and hand watered twice daily. Seedlings were counted twice weekly for 6 weeks (post-sowing), until 8 January 1987.

Results and Discussion

Dimensions and weight of 100 seeds of each species were measured (Table 14).

Numbers of germinants were analysed as a completely randomized design by the ANOVA method, using the SAS statistical package. This indicated a significant interaction between sowing depth and species (Table 15).

This appears to be the result of relatively good germination of *Eucalyptus* spp. (Fig. 9) compared with *Acacia* spp. in the surface sowing treatment (Fig. 10). The large-seeded *Eucalyptus calophylla* (Table 14) was an exception, demonstrating poor soil-surface germination. *Eucalyptus loxophleba* and *E. camaldulensis* germinated

TABLE 14

Germination rates for species used for the Effects of Soil Depth on Seed Germination Experiment.

SPECIES	CALM SEED LOT NO.	EXPECTED GERMINANTS PER GRAM	PERCENTAGE VIABILITY	WEIGHT OF 100 SEEDS (g)
Eucalyptus calophylla	D890	5	54	9.70
E. camaldulensis	D249	158	75	0.48
E. erythrocorys	D289	NA	NA	0.90
E. loxophleba	D342	910	50	0.03
Acacia acuminata	D347	47	70	1.53
A. dealbata	D002	NA	65	1.39
A. helmsii	8492	NA	NA	2.90
A. microbotrya	D348	22	74	3.38
Allocasuarina huegeliana	D358	298	60	0.20

poorly in the 5-10 mm soil-depth treatment but was inconsistent in the other treatments (Fig. 9).

Surface sowing of the *Acacia* species tested here is unlikely to produce good field results, and depths exceeding 2 mm would be required for successful germination (Fig. 10). These data support the hypothesis that larger-seeded species require greater sowing depth. These results, although based on a small data set are consistent with results of previous field experiments (discussed in this paper) and South Australian field experiments summarized by Panetta and Groves (1990).

TABLE 15

ANOVA of germinants for nine tree species sown at three depths in the Effects of Soil Depth on Seed Germination Experiment.

EFFECT	DF	MS	F
Depth	2	960.13	100.09 ***
Species	8	165.49	17.25 ***
Depth x Species	16	165.84	17.29 ***
Error	27	9.59	

* $P < 0.001$
** $P < 0.0005$
*** $P < 0.0001$

EFFECTS OF PRE-EMERGENT HERBICIDE ON SEED GERMINATION EXPERIMENT

Background

A major problem associated with direct seeding on existing farmland, in contrast to new farmland or mined areas, is competition from exotic grasses and broad-leaved weeds (McMurray 1985). Adequate weed control must be maintained into the first summer if establishment is to be successful.

Use of suitable non-selective herbicides such as atrazine (residual) in conjunction with amitrole (contact), at recommended rates, can ensure good weed control for lengthy periods. However, the readily available mixtures of atrazine and amitrole (e.g. *Vorox AA*®), when applied at rates sufficient to provide adequate weed control, have been observed to inhibit germination and have a deleterious effect on seedlings (CALM 1988).

Atrazine is a residual herbicide that is translocated on root uptake and can remain active in the soil for up to four weeks depending on the amount of moisture in the soil. Atrazine provides useful control of grasses and broad-leaf weed seedlings, but can be particularly toxic to native species (Swarbrick 1984). Amitrole is a translocatable foliar herbicide for control of a range of weed species. Amitrole can also remain active in the soil for varying periods, depending on the level of soil moisture (Swarbrick 1984).

An experiment was established to assess whether atrazine, amitrole and the commercial mix of the two (at recommended rates) adversely affect the germination and emergence of a range of native tree species when applied prior to sowing.

Methods

A completely randomized block design was used with treatments being species, herbicide rate and herbicide timing. The experiment was carried out under controlled conditions in the CALM nursery at Narrogin.

Six eucalypts, *Eucalyptus calophylla*, *E. gomphocephala*, *E. loxophleba*, *E. maculata*,

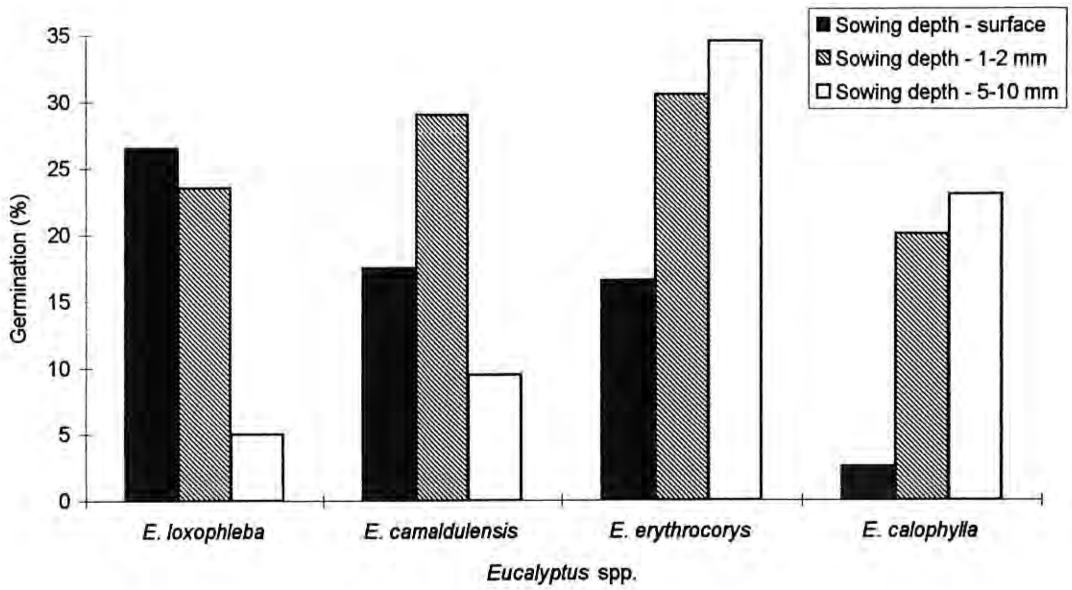

Figure 9. Percentage germination at various depths for four eucalypt species in the Effects of Soil Depth on Seed Germination Experiment.

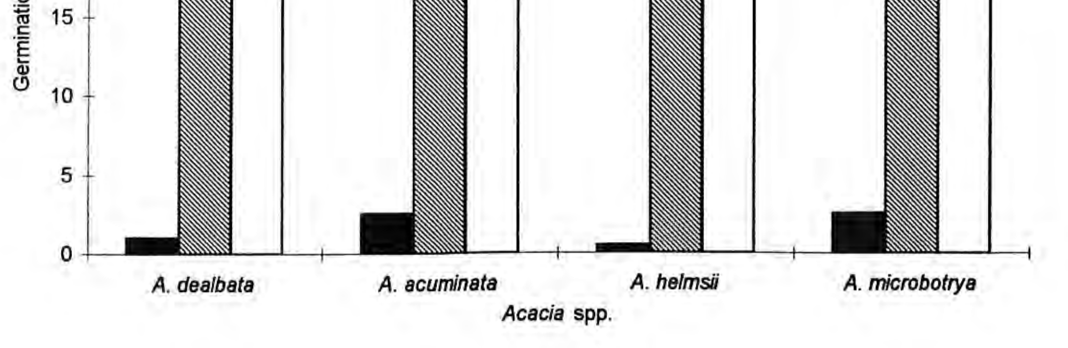

Figure 10. Percentage germination at various depths for four species of Acacia in the Effects of Soil Depth on Seed Germination Experiment.

E. muelleriana and *E. patens* were chosen as representative of various seed sizes and sub-genera. *Allocasuarina huegeliana, Acacia acuminata* and *A. saligna* were also included in the experiment for comparison. All of these species are commonly used in direct seeding revegetation programs in the wheatbelt.

Herbicide treatments of atrazine and amitrole were applied singly and combined[14] as follows:

amitrole 2 L ha^{-1}
amitrole 4 L ha^{-1}
atrazine 2 L ha^{-1}
atrazine 4 L ha^{-1}
atrazine 2 L ha^{-1} and amitrole 2 L ha^{-1}
atrazine 4 L ha^{-1} and amitrole 2 L ha^{-1}
atrazine 2 L ha^{-1} and amitrole 4 L ha^{-1}
atrazine 4 L ha^{-1} and amitrole 4 L ha^{-1}
Control, no herbicide application

Herbicides were applied using a knapsack sprayer with a 1-m (4 nozzle) boom. Following each spraying, trays containing seedlings were placed unwatered on raised beds for 24 hours. Two application times for the herbicide treatments were also tested.

Herbicides were (1) applied 14 days prior to sowing and (2) applied immediately prior to sowing. Spraying treatments were applied by hand away from the experimental area to avoid contamination.

Lots of 30 seeds were counted out for large-seeded *Acacia acuminata, A. saligna* and *Eucalyptus calophylla* and weighed in 0.1 g lots for the remaining eucalypts and *Allocasuarina huegeliana*. Standard seedling trays filled with sterilized soil mix were used as replications for the experiment. Seed lots, according to species mix, were sown onto the soil surface and lightly covered with 3 mm of soil. Seeded trays were placed on raised beds under 70 per cent shade cloth to germinate.

Seedlings were watered by hand as required, with care taken to ensure they were not flooded throughout the assessment period.

The systemic fungicide *Bavastin*® was applied at regular intervals to control the fungus *Botrytis cinerea* that developed on some seedlings.

Results and Discussion

Final percentage germination was poor for several species with relatively low germination (Table 16) and this is likely to have affected results. Low germination for *Acacia* spp. concurs with results in previous experiments discussed in this paper and may indicate failure of the pre-sowing seed preparation. *Allocasuarina huegeliana* and *Eucalyptus loxophleba* also had relatively poor germination and this is more likely to be owing to the effects of the herbicide treatments. These two species performed well in previous experiments.

Analysis of variance indicated a number of significant first order interactions (Table 17). However, the magnitude of these interactions is small relative to the main treatment effects; we therefore discount these interactions as unlikely to be of major practical importance.

As expected, species germination response was highly variable (unpublished data). Combined data of all species revealed that all treatments compared with the control, showed greatly reduced numbers of germinants (Fig. 11). Application of combined herbicides resulted in lower germination. Mean germination for amitrole at 2 L ha^{-1} was relatively high, but not significantly different from the control (Fig. 11).

Significant differences occurred in germination response between application times for herbicide treatments (Table 17). Data represented a range of herbicide combinations at different rates, and as for species, showed considerable variation. However, there was no interaction between application time and species or treatment (Table 17). Mean number of seedlings recorded for herbicide application two weeks prior to sowing was 3.85 compared with 5.59 for the herbicide application at sowing time treatment. This reflects the ability of seedlings to tolerate amitrole, and survive atrazine best before the period of maximal herbicide activity.

All herbicide treatments resulted in reduced numbers of germinants. However, herbicides (or other weed control strategies) are necessary to reduce competition from weeds in seedling establishment; particularly in revegetation projects involving native species (Panetta and Groves 1990). The use of herbicides is therefore a trade-off between deaths from weed competition and herbicide toxicity. Increased survival and performance of seedlings because of reduced competition from weeds was not included here. Recent work on the use of newer and more effective herbicides has been referred to in discussions of other experiments.

CONCLUSIONS

The Experiments

Despite variability, results of these experiments support information compiled from successful direct seeding practitioners (Runciman personal communication). Direct seeding is a cost-effective method for individual farmers and community groups to revegetate large areas of old farmland. It will be increasingly important in assisting land managers to control and prevent land degradation in the wheatbelt (Greening WA 1992). The relevance to contemporary revegetation practices is the potential contribution of direct seeding to the enormous scale of tree planting expected in Australia by various agencies, e.g. one billion trees by the year 2000 (Hawke 1989).

The following summaries are collated from the results of experiments discussed previously in the paper.

[14] The highest application rate used in the experiment was based on the recommended rate for *Vorox AA*, i.e. atrazine and amitrol combined (Swarbrick 1984). Other treatments were a derivation of this rate, although component formulations and recommended rates for the separate chemicals are different.

TABLE 16

Species and rates of germination for the Effects of Pre-emergent Herbicide on Seed Germination Experiment.

SPECIES	SEED LOT NO.	SEEDS SOWN PER TRAY	EXPECTED NO. OF GERMINANTS	OBSERVED NO. OF GERMINANTS	GERMINATION (%)
Acacia acuminata	6809	30	21	2.83	13.5
A. saligna	D1017	30	18	2.17	12.1
Eucalyptus patens	D66	0.1 g	4	7.67	191.0
E. loxophleba	D342	0.1 g	47	2.89	6.1
E. calophylla	D890	30	15	8.44	56.3
E. gomphocephala	D384	0.1 g	11	5.94	54.0
E. maculata	D85	0.1 g	4	1.89	47.2
E. muelleriana	D365	0.1 g	4	4.72	118.0
Allocasuarina huegeliana	D352	0.1 g	30	5.94	19.8

TABLE 17

ANOVA of number of germinants in the Effects of Pre-emergent Herbicide on Seed Germination Experiment.

EFFECT	DF	MS	F
Treatment (Tr)	8	213.00	23.69 ***
Time (Ti)	1	122.72	13.65 **
Species (S)	8	105.75	11.76 ***
Tr x Ti	8	16.17	1.80
Tr x S	64	28.84	3.21 ***
Ti x S	8	16.14	1.80

* $P < 0.001$
** $P < 0.0005$
*** $P < 0.0001$

Weed Control

No single weed control treatment gave consistently good results, although it was clear that successful establishment was associated with good weed control. Scalping to a depth of 5-10 cm, with the exception of the Narrogin Direct Seeding Experiment in 1985, provided better weed treatments. However, there are two concerns about the use of this treatment for direct seeding. Firstly, scalping has been observed to inhibit growth and development of trees, particularly *Eucalyptus* species, at some of the experiment sites several years after seeding. Secondly, it is not common weed control practice in the wheatbelt and use of the heavy machinery required may be expensive.

Pre-sowing use of an amitrole-atrazine mix (i.e. the herbicide *Vorox AA*®), combined with cultivation, gave acceptable results in field experiments. Variable results were achieved in the field using either cultivation, paraquat-diquat or atrazine. Amitrole at low rates, and with various rates of atrazine, favoured germination under nursery conditions.

Although current research is providing effective herbicides for post-emergent control of grasses and some broad-leaf weeds, pre-sowing weed control is highly desirable. Early control of weeds and reduction in weed seed banks in the soil, without the constraints of newly established native plants is more practical and effective for direct seeding methods. Long-term weed management strategies based on individual site conditions and weed flora are essential to give best direct seeding results.

Sowing Methods

Variations in sowing methods, used in an attempt to increase germination, were ineffective in the two experiments where they were introduced. Post-sowing compaction had no apparent effect at three wheatbelt sites. Different sowing methods produced no apparent gain in germination in an experiment near Narrogin, although many species failed because of waterlogged soils and soil salinity. *Acacia* species, which dominated this experiment, were favoured by deep sowing.

This result supported the nursery experiment that indicated depth of sowing requirements for a range of native species depending on their seed size. Large-seeded trees and shrubs, particularly *Acacia* spp. and *Eucalyptus calophylla*, required soil covering of 5-10 mm. Smaller-seeded *Eucalyptus* spp. preferred a soil covering of 2-5 mm; although good results were achieved for some species by surface sowing.

The sowing of large- and small-seeded species together may require a sowing depth compromise, or two passes of the seeding machine, sowing the large-seeded species first.

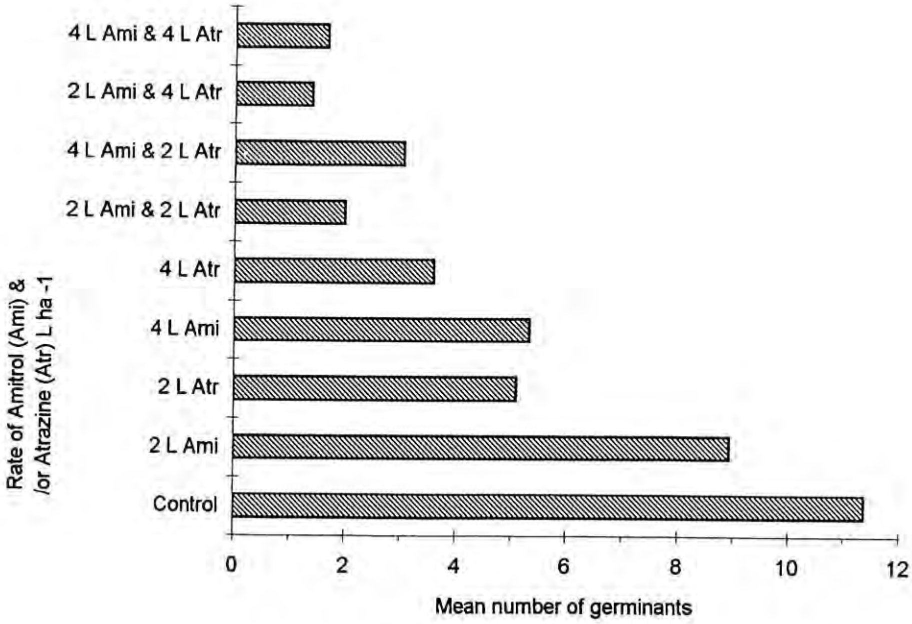

Figure 11. Mean number of germinants for the herbicide treatments for Effects of Pre-emergent Herbicide on Seed Germination Experiment.

Sowing Time

Sowing time was an important variable in the results of three major field experiments. The earlier sowing time produced markedly increased germination response in separate experiments in the Narrogin Direct Seeding Experiment site in June 1984, July 1985 and July 1986. July sowing times produced better results in experiments at three other wheatbelt locations in 1986.

Establishment of *Acacia* spp. was favoured by May and June sowing times rather than July for the establishment techniques experiment near Narrogin in 1987. These sowings were late autumn-early winter and slight differences in results probably reflect rainfall distribution for that year rather than early or late seasonal timing of the direct seeding operation.

For wheatbelt climatic conditions of low seasonal rainfall comprising wet winters and dry summers, direct seeding in late June or in July offers considerable advantages over later, August or September, sowings.

Species Suitability

A major result of these experiments is that the species tested responded differently to site, weed control and soil preparation factors. Examples included differences between large- and small-seeded species and differences between *Eucalyptus* spp., and *Acacia* spp. and *Allocasuarina huegeliana*. As previously mentioned, *Acacia* species succeeded at only one site, where the soils were waterlogged and slightly saline, and the large-seeded *E. calophylla* failed at all sites. The failure of large-seeded species is mostly owing to the method of hand sowing on the soil surface.

Eucalypt species performed variably in the three major field experiments. *E. loxophleba* performed most consistently, although it was not the best species at any site. *E.wandoo* was best performer in separate experiments at the Narrogin site and at the Jerramungup site, but was extremely variable in the Optimum Techniques Experiment at the other Narrogin site. Numbers of germinants at both of the latter sites were relatively low.

Tuart *(E. gomphocephala)* and pricklybark *(E. todtiana)* were used only in the Broadscale Direct Seeding Techniques Experiment. Both species performed relatively well compared with other species, although their performance was only 25 per cent of that of *Allocasuarina huegeliana*, the best species in the experiment.

Allocasuarina huegeliana had the highest relative establishment rate and the best seedling survival of all species tested in the experiments. Although wide variations between and within sites were found, this species demonstrated high tolerance of sowing methods, weed control techniques, sowing times and soil preparation. Despite its palatability to grazing animals, this and other local species in the genera *Allocasuarina* and *Casuarina* should be included in seed mixes for direct seeding experiments, as survival is likely even in poor conditions.

Further Research

In order to refine the techniques of direct seeding, more experimental research is needed on all topics mentioned here. Many demonstration experiments have been established in the wheatbelt but the results of these are difficult to assess and sometimes misleading. This is owing to the combination of factors relating to the year and time of sowing, weed control method and species characteristics. Many experiments are not replicated and do not allow for the analysis of interaction between factors. However, Greening WA (1992) have reported some common parameters for these factors, after conducting a review of a large number of these experiments.

Long-term monitoring of direct seeding experiments is important to enable assessment where details of these factors have been recorded. Germination and establishment success for many species do not necessarily translate directly into good long-term performance.

ACKNOWLEDGEMENTS

The direct seeding projects discussed here (many more were established, but only a few were suitable for publication) and the ensuing analysis and reporting of results took place over nine years (1984 - 1993). The authors wish to thank the many people involved and apologize to anyone not mentioned below.

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REFERENCES

Andrew, I. (1984). Simple experimental design for forestry field trials. *New Zealand Forest Service FRI Bulletin* No. 71.

Anon. (1991). Narrogin Rainfall Records. In: *Narrogin Observer.* Narrogin, Western Australia.

Bird, R., Cumming, K.N. and Kearney, G.A.(1990). Research in direct seeding of trees in the 500 - 800 mm rainfall zone of western Victoria. In: *Sowing the Seeds,* Proceedings of conference on direct seeding and natural regeneration, Adelaide, May 1990. pp 65-74. Greening Australia, Canberra.

Boland, D.J., Brooker, M.I.H., Chippendale, G.M., Hall, N., Hyland, B.P.M., Johnston, R.D., Kleinig, D.A. and Turner, J.D. (1984). *Forest trees of Australia.* Nelson-CSIRO, Melbourne.

Brooker, M.I.H and Hopper,S.D. (1991). A taxonomic revision of *Eucalyptus wandoo, E. redunca* and allied species (*Eucalyptus* series *Levispermae* Maiden - Myrtaceae) in Western Australia. *Nuytsia* **8** (1), 1-188.

Brooks, D.R. and Jeffries, M.(1990). Regeneration of coastal dune environments. In: *Sowing the Seeds,* Proceedings of conference on direct seeding and natural regeneration, Adelaide, May 1990, pp 27-34. Greening Australia, Canberra.

Buchanan, R. (1989). *Regenerating Australian Landscapes.* NSW TAFE Publications, Sydney.

Buchhorn, R., Jones, D. and Robertson, D. (1989). *Urban forestry handbook: a guide to the management of urban bushlands.* Department of Conservation, Forests and Lands, Melbourne.

Bureau of Meteorology (1965). *Climatic survey, Region 11 - Great Southern, Western Australia.* Commonwealth of Australia, Melbourne.

CALM (1988). Broadscale direct seeding of trees on farms. *Department of Conservation and Land Management Information Sheet* No. 2-88.

Castles, I. (1992). *Australia's environment: issues and facts.* Australian Bureau of Statistics, Canberra.

Cochran, W.G. and Cox, G.M. (1957). *Experimental Designs.* 2nd edn. Wiley & Sons, New York.

Copley, P.B. and Venning, J. (1983). *Rural Revegetation in South Australia.* Department of Environment and Planning (South Australia), Adelaide.

Dalton, G. (1990). Direct seeding in southern South Australia. In: *Sowing the Seeds,* Proceeding of conference on direct seeding and natural regeneration, Adelaide, May 1990. pp. 75-80. Greening Australia, Canberra.

Edmiston, R. (1985). Direct seeding in the wheatbelt areas of Western Australia. In: *Revegetation workshop: direct seeding and natural regeneration techniques,* Proceedings of workshop held in Adelaide 27-29 March, 1985. J. Venning (ed.). pp. 36-40. Department of Environment and Planning (South Australia), and Greening Australia (SA), Adelaide.

Greening Australia (1990). *Sowing the Seeds*, Proceedings of conference on direct seeding and natural regeneration, Adelaide, May 1990. Greening Australia, Canberra.

Greening WA (1992). *Direct seeding of trees and shrubs in Western Australia*. Greening Western Australia and Western Australian Department of Agriculture, Perth.

Grewer, G. (1988) Direct seeding of trees . In: *The Esperance Tree Book*. pp. 37-48. Esperance Soil Conservation District Advisory Committee, Esperance WA.

Hawke, R.J.L. (1989). Our country - our future: statement on the environment: executive summary. Australian Government Publishing Service, Canberra.

Hobbs, R.J.(1993) Can revegetation assist in the conservation of biodiversity in agricultural areas. *Pacific Conservation Biology* **1**, 29-38.

Hobbs R.J. and Saunders D.A., (1991). Reintegrating fragmented landscapes - a preliminary framework for the Western Australian wheatbelt. *Journal of Environmental Management* **33**, 161-167.

Loney, B. (1990). Direct seeding in Western Australia - It's status and future. In: *Sowing the Seeds*, Proceedings of conference on direct seeding and natural regeneration, Adelaide, May 1990. pp 103-112. Greening Australia, Canberra.

Malcolm, C.V. (1990). Rehabilitation agronomy - guidelines for revegetating degraded land. In: Australian ecosystems: 200 years of utilization degradation and reconstruction, Proceedings of a symposium held in Geraldton, WA 28 Aug-2 Sep 1988. D.A. Saunders, A.J.M. Hopkins and R.A. How (eds). *Proceedings of the Ecological Society of Australia* **16**, 551-556.

McMurry, S. (1985). Post-emergent herbicides for weed control with direct seeded native species. In: *Regeneration workshop: direct seeding and natural regeneration techniques*. Proceedings of workshop held in Adelaide 27-29 March 1985. J. Venning (ed.). Department of. Environment and Planning (South Australia), Adelaide.

Monk, D., Pate, P.S. and Loneragan, W.A. (1981). Biology of *Acacia pulchella* R.Br. with special reference to symbiotic nitrogen fixation. *Australian Journal of Botany* **29**, 579-592

Negus, T. (1992). New herbicide for weeds in young eucalypts. *Department of Agriculture (Narrogin Advisory District, Western Australia) Memo - to the Farmer* **18**(4), 16.

Panetta, F.D. and Groves, R.H. (1990). Weed management and revegetation programmes. *Proceedings of the Ecological Society of Australia* **16**, 537-543.

Pigott, J.P. (1989). Lupin control in remnant woodland. *Australian Weeds Research Newsletter* **38**, 59-61.

Pigott, J.P. (1993). Management of native woody vegetation on farms in Western Australia. Paper presented at The Role of Trees in Sustainable Agriculture Conference, Albury 1991. In Scott, P.R. (Ed.) *The Role of Trees in Sustainable Agriculture: A National Conference - Reprints of the Western Australian papers*, pp. 27-47 Native Vegetation. Resource Management Technical Report 138, Department of Agriculture, Western Australia.

Richards, D. and Beardsell, D.V. (1987). Seed dormancy. In: *Germination of Australian native plant seed*. P.J. Langkamp (ed.). pp.1-13. Inkata Press, Melbourne.

Saunders, D.A. and Curry, P.J., (1990). The impact of agricultural and pastoral industries on birds in the southern half of Western Australia: past, present and future. In Australian Ecosystems: 200 years of utilization degradation and reconstruction. D.A. Saunders, A.J.M. Hopkins, and R.A. How (eds). *Proceedings of the Ecological Society of Australia* **16**, 303-321.

Schofield, N.J., Bari, M.A., Bell, D.T., Boddington, W.J., George, R.J. and Petit, N.E. (1993). The role of trees in land and stream salinity control in Australia. Paper presented at The Role of Trees in Sustainable Agriculture Conference, Albury 1991. In Scott, P.R. (Ed.) *The Role of Trees in Sustainable Agriculture: A National Conference - Reprints of the Western Australian papers*, pp. 21-43 Salinity. Resource Management Technical Report 138, Department of Agriculture, Western Australia.

Snedecor, G.W. and Cochran, W.G. (1980). *Statistical Methods*. 7th edn. Iowa State University Press, Ames, Iowa USA.

Stoneman, T.C. (1991). An introduction to the soils of the Narrogin Advisory District. *Department of Agriculture (Western Australian) Bulletin* 4221.

Swarbrick, J. (1984). *Australian Weed Control Handbook*. 7th edn. Inkata Press, Melbourne.

Venning, J. (ed.)(1985). Revegetation Workshop: Direct seeding and Natural regeneration techniques. Proceedings of workshop held in Adelaide 27-29 March, 1985. Department of Environment and Planning (South Australia), and Greening Australia (SA), Adelaide.

Venning, J. (1988). *Growing trees for farms, parks and roadsides: a revegetation manual*. Lothian Publishing Company, Melbourne.

Venning, J. and Croft, T.S. (1985). *1984 regeneration trials*. Department of Environment and Planning (South Australia), Adelaide.

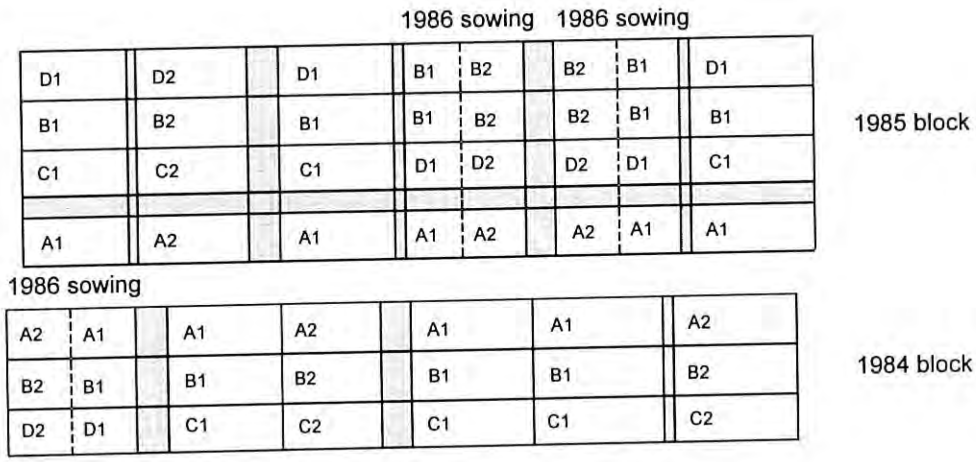
Walden, J.F.(1982). *Conservation and regeneration techniques*. Main Roads Department (Western Australia), Perth.

WA Parliament (1990). *Discussion Paper No. 2: Agricultural Regions of WA*. Select Committee into Land Conservation, Legislative Assembly, Perth, WA.

Webb, M. (1991). An evaluation of pre- and post-emergent herbicides on Australian native plants used for cut flower and foliage production. *Department of Agriculture (Western Australia) Technote* No. 15/91.

APPENDIX 1

Layout of direct seeding treatments for the Narrogin Agricultural College Direct Seeding Trial.



Key to treatments

Weed control

A. Scalping
B. Paraquat/ diquat
C. Amitrole/ atrazine
D. Atrazine

Sowing time

1. Early
2. Late

NB. Shaded strips are buffers.