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The Effect of Sowing Season on the Reliability of Direct Seeding

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Foreword

Direct seeding is a common and important revegetation practice used throughout temperate Australia. This report examines the effect of direct seeding at different times of the year on germination and survival of native tree and shrub species at two sites. The trials showed that some species have better survival when sown in a particular season. This has implications for direct seeding practitioners, who need to make regular observations of their own sowings to determine the preferred season for the species that they use. The trials reinforced the common practice of sowing seed in the period from late autumn to early spring in southern Australia.

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This report is an addition to RIRDC's diverse range of over 1600 research publications. It forms part of our Agroforestry and Farm Forestry R&D program, which aims to integrate sustainable and productive agroforestry within Australian farming systems. The JVAP, under this program, is managed by RIRDC.

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Summary

What the report is about

This report is about improving the reliability of direct seeding of native tree and shrub species, through matching field sowing times to germination requirements of species. Two pilot experiments were carried out in low rainfall areas of South Australia and Victoria to determine the effects of direct seeding at different times of the year. Sowings occurred between September 2004 and September 2005 and monitoring occurred until August 2006. Rainfall during this period was below the long term average. The differences in germination and survival among sowings carried out in spring, summer, autumn and winter are reported for the eight native tree and shrub species used. The report recommends greater monitoring of germination and survival by direct seeding practitioners, to determine optimum sowing times for common revegetation species.

Who is the report targeted at?

This report is targeted at direct seeding practitioners, both new and experienced, working in temperate Australia. It is also relevant to people and organisations who plan, prioritise and fund direct seeding work in these areas, such as landholders, catchment management organisations and community groups. The research recommendations are relevant to research organisations such as universities, state government departments and CSIRO.

Background

Under the Australian Government's National Action Plan for Salinity and Water Quality, and the Natural Heritage Trust, regional organisations have set ambitious targets to revegetate large areas of land to improve natural resource management. The cost of meeting these targets through tubestock (seedling) planting alone is prohibitive. If these targets are to be achieved, costs must be reduced and some commercial return from the plantings will be necessary. Direct seeding costs less than planting with tubestock seedlings, but can be less reliable. Improving the reliability of direct seeding will reduce establishment costs for both environmental and commercial revegetation, and reduce the quantities of seed required. Understanding which species are favoured by sowing at particular times of the year will enable practitioners to make better use of scarce seed resources. Direct seeding of commercial species in a wide range of environments will also be necessary to reduce costs and increase returns from revegetation.

In 2003-04 a review was carried out to determine whether there were any advances that could be made to the technique of direct seeding, to increase its reliability to the point where it could be used in commercial revegetation, such as oil mallee plantations. This review included four consultation workshops with leading direct seeding practitioners in temperate Australia, and a literature review. One of the recommendations from this review was to conduct a small research project to confirm the effects of sowing at different times of the year. To use less seed in direct seeding, we need to ensure that seed is sown when it has the highest chance of germinating, in order to avoid losses from predation, desiccation and disease.

Aims/Objectives

The trial aimed to determine whether:

1. Some species are favoured by sowing at different times of the year, and whether the differences in survival between species are great enough to recommend multiple sowings. The trial was not intended to make recommendations for all species used in direct seeding; rather to see if there was evidence for an effect in the field, which could be elaborated further with local research using species mixes commonly used by practitioners.
2. One particular time of the year was better for direct seeding at these sites than another. Note that this project only sowed trials within one 12 month period.

3. The use of a commercially available *Bradyrhizobium* inoculant affected the survival of the acacias in the trial and whether there was a differential effect over the four sowing times.

Methods used

Trial sites were established in South Australia (near Palmer), northern Victoria (near Pyramid Hill) and Western Australia (near Northam), although the latter site was abandoned early due to drought and grasshopper predation and is not reported here. The trials used a mix of eight acacia and eucalypt species native to the study areas.

At each site, four sowings of the mix of eight local native species were carried out, with one sowing occurring in each of spring, summer, autumn and winter. Sowings occurred between September 2004 and September 2005, and these were monitored sporadically until August 2006 at Palmer and May 2006 at Pyramid Hill. The trial used a randomised split plot design, with time of sowing as the main effect and presence or absence of inoculant assigned to subplots. The number of germinants per species was monitored from a sample of the trial plots for each sowing. Both trials were sown using modified Burford seeders, which are commonly used in these areas.

Results/Key findings

The climate during this trial (September 2004 to August 2006) was different from average long term trends, with a late arrival of the 'autumn break', hotter than average summer temperatures in 2005 and 2006, and rainfall at Palmer was considerably below average from October 2005 to August 2006.

Although limited in scope, the trials found that there were differences in germination and survival among the four different sowing times. As expected, the summer sowing had the poorest survival. Autumn and spring sowings gave the best survival at both sites, with winter sowings also giving good results at Palmer. This confirms current practice in these areas.

Significantly, there were differences in survival for individual species across the four sowing times. For example, at Pyramid Hill, *Acacia pycnantha* and *A. acinacea* were strongly favoured by sowing in autumn while *Eucalyptus microcarpa* was strongly favoured by an early spring sowing.

There were some significant differences in survival of the *Acacia* species between those inoculated with *Bradyrhizobium* and those not, but only at the Pyramid Hill site. At Pyramid Hill, the better survival in inoculated acacias was only for the autumn and winter sowings. At Palmer, the germination of the two acacia species was low and the differences between inoculation treatments were not significant. However uninoculated *Acacia* had slightly higher germination than inoculated in spring and winter.

It appears that the use of the inoculant 'Wattle Grow' improved the survival of the two *Acacia* species at Pyramid Hill compared to the uninoculated plants. This supports other studies that show that the inoculant helps survival by increasing the effectiveness of the root system in gaining access to soil moisture. Further trials are needed.

Recommendations

The implication of these results for direct seeding practitioners is that despite the best efforts at site preparation and planning, if the whole suite of species is sown together at a particular site in a particular season it is unlikely all species will germinate and survive. Sowing times and seed mixes may need to be altered to reflect species' preferred sowing seasons.

Until we can more precisely predict the range of environmental conditions that favour germination and early survival for all of our common species, practitioners must rely on observations they make in the field. This presents a strong case for regular monitoring of sites for several years after sowing.

Simple methods such as counting the number of germinants over a sample length of seeding line for each species will give an indication of success. These records can then be compared with site specific weather records to give an indication of how the conditions affected the germination and survival of individual species used on the site. Practitioners will then be able to build up a picture over time of which species are favoured by certain conditions.

The ideal moisture, light and temperature regimes for individual species should also be verified experimentally. This could then be matched to long-term climate averages for particular regions to predict the optimum sowing windows for individual species. The effect of inoculants such as 'Wattle Grow' should also be further tested for a range of *Acacia* species sown in different seasons and sites.

Direct seeding practitioners cannot be expected to bear the burden of this monitoring alone. Catchment authorities and other regional organisations should assist or carry out the monitoring. Funding bodies, principally the Australian Government through the Natural Heritage Trust, should make monitoring and reporting a condition of funding. To effectively achieve a national picture of species response to sowing times and climatic conditions, a national monitoring and reporting program should be established. Such a program would provide a simple method for field officers to use and a web-based database for reporting the results. Sufficient funding would also need to be provided to enable field collection of data, data entry and analysis to be undertaken. A critical component of such a system will be its ability to provide meaningful recommendations back to direct seeding practitioners. Regional universities and state research agencies could also assist, in order to build up a picture of the conditions favoured by common revegetation species in direct seeding. Practitioners could then add to their existing experiential knowledge to determine if particular sites and species warrant separate sowings at different times of the year. Such research should initially target species of high commercial or conservation value.

Introduction

Under the Australian Government's National Action Plan for Salinity and Water Quality, and the Natural Heritage Trust, regional organisations have set ambitious targets to revegetate large areas of land to improve natural resource management. The cost of meeting these targets through tubestock (seedling) planting alone is prohibitive. If these targets are to be achieved, costs must be reduced and some commercial return from the plantings will be necessary. Direct seeding is lower cost than planting with tubestock seedlings, but can be less reliable. Improving the reliability of direct seeding will reduce establishment costs for both environmental and commercial revegetation, and reduce the quantities of seed required. Understanding which species are favoured by sowing at particular times of the year will enable practitioners to make better use of scarce seed resources. Direct seeding of commercial species in a wide range of environments will also be necessary to reduce costs and increase returns from revegetation.

In 2003 and 2004 Greening Australia led a review of direct seeding in Australia with a view to identifying advances that could be made to make direct seeding more reliable for large-scale revegetation work. This review (Carr *et al.*, in press) was funded by the Joint Venture Agroforestry Program.

During this review phase, a number of research actions were highlighted after consultation with direct seeding practitioners in four states. One of the research priorities determined by the workshops was to examine the influence of climate and season on the germination and survival of direct seeded plants. There appears to be considerable variation both between and within regions based on the timing of sowing, the climatic triggers for commencement of the "direct-seeding season", the time at which direct seeding is finished, the extent to which direct sowings are made on opportunistic rainfall and the relationship between time of year, germination success and survival of germinants. In some regions, particularly central and northern NSW, seasonal variation appears to be the main reason for mixed success in germination, with a resulting inability to predict germination with any success. In other regions, seasonal variation has an impact on the success of different species.

In most temperate regions direct seeding is carried out in a limited window, usually after the "autumn break" and before summer temperatures get too high. However, there is little monitoring of the success of plantings at different times, nor analysis to determine if autumn plantings do better than spring plantings etc. During the workshops, there was considerable speculation about the impact of the timing of planting, but with no hard evidence to back it up. If the climatic conditions that favour optimal germination could be determined, the window for sowing could be matched to current seasonal conditions (both actual and predicted) using climate tools such as Long Paddock and AusGrass. This would allow for better conservation of seed in dry years and a longer season in wetter years.

The aim of the project described here is to begin to test the effect of seasonal conditions on direct seeding success.

Methods and materials

Sites

Three trial sites in temperate Australia were selected: Pyramid Hill, in northern Victoria; Palmer, in south east South Australia; and Northam, in Western Australia. These sites represented areas where participants in the direct seeding workshops carried out extensive direct seeding work.

Palmer, South Australia

Located on the property 'Wallowa', near Palmer, this site (Latitude 32° 52'S, Longitude 139° 08' 48"E) is on former sheep grazing land, in a valley between steeply sloping hills. The site has a gentle (15-25°) slope to the south, with full sun. The soil is well-drained gravelly, red sandy loam, with a brownish red surface. It is calcareous at depth. The soil at the site sets hard on the surface in summer, but is soft and friable when moist. The native vegetation at the site was formerly acacia shrubland. The mean annual rainfall is 345 mm (Pallamana PO). This site is fairly typical of the soils and vegetation found on the eastern side of the Adelaide Hills and throughout the southern Flinders Ranges and northern agricultural zones of South Australia.

Pyramid Hill, Victoria

Located on the property 'Mt Hope Run' near Pyramid Hill in northern Victoria this site is at latitude 36° 03' and longitude 144° 06'. The trial site was grazed by sheep prior to the trial and had previously been used for cropping. It is a north facing site with a 5° slope. The soil is a sandy loam derived from granite, with a pH of 5.5 on the surface. At 600mm depth the soil is red clay with a pH of 9.5. The soil has a hard-setting surface when dry. The native vegetation on the site was formerly Pine-Buloke-Box Woodland (*Callitris glaucophylla*, *Allocasuarina luehmannii*, *Eucalyptus microcarpa*, *E. melliodora*), remnants of which still exist adjacent to the site. The mean annual rainfall is 373 mm (Kerang). This site is typical of many similar sites in northern Victoria (west of the Mallee) and southern NSW.

Northam, Western Australia

This site was located on an agricultural research station adjacent to the town of Northam in Western Australia. The soil is sand with a pH of 5.5 on the surface. This site suffered severe drought and grasshopper predation during the trial and was abandoned after one sowing as there was unlikely to be any growth or survival.

Experimental design

The trial used a randomised split-plot design, with four replicates. Season of sowing was the main treatment. 'Wattle Grow', a *Bradyrhizobium* inoculant (Thrall *et al.*, 2001), was also applied as a sub-plot treatment, at a rate of 300g/100m. Each treatment was applied to two 100m long strips of single row direct seeding, one with 'Wattle Grow' and the other without. Figure 1 shows the trial design and the randomisation of treatments.

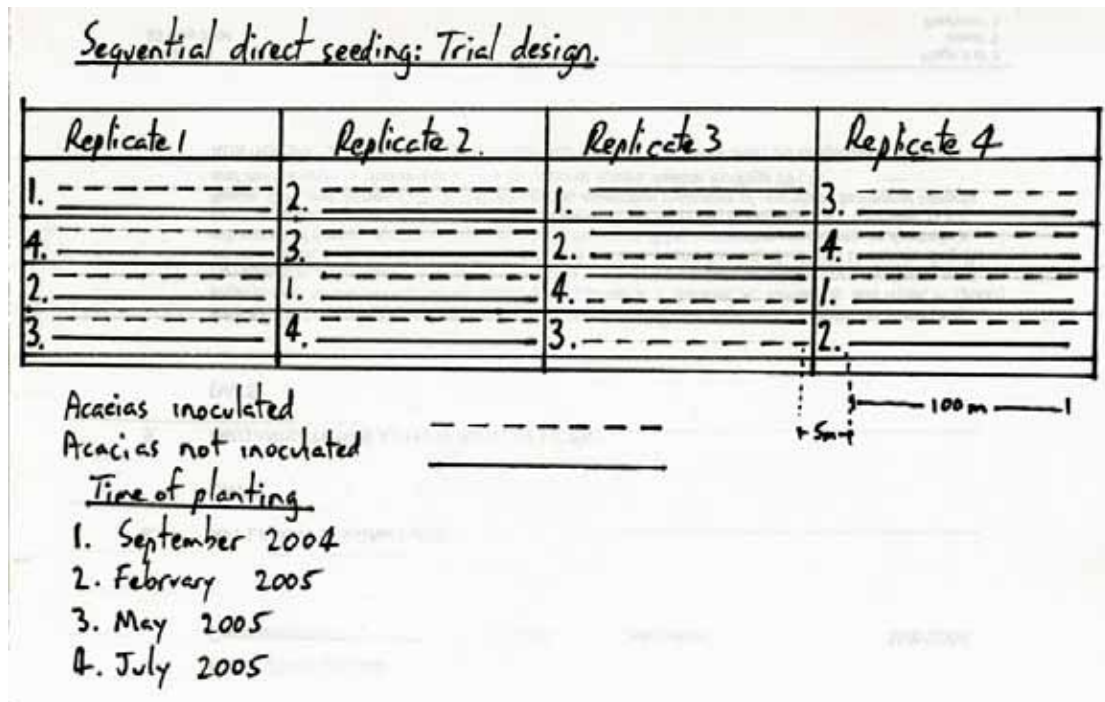


Figure 1: Trial design.

A standard mix of seed of local species was developed for each site, chosen to represent species with reliable germination, commonly used in the district for direct seeding and to represent a range of genera. This mix was used in all four sowings in the same ratios. Seed was applied at 500g/km. Table 1 shows the species used at each site and the rate at which they were used. Seed viability was tested for all seedlots using simple cut tests and germination tests and found to be higher than 80% for all seedlots.

Table 1: Species and rates used at Palmer and Pyramid Hill trial sites

Species	Provenance	Rate (g/100m plot)
Palmer		
<i>Acacia euthycarpa</i> *	Tailem Bend D021203	15
<i>Acacia ligulata</i>	Waikerie D160105	15
<i>Allocasuarina verticillata</i>	'Wallowa'	7
<i>Atriplex rhagodioides</i>	Mannum D170404	7
<i>Callitris gracilis</i> **	Murray Bridge M2 81103	7
<i>Eucalyptus porosa</i>	Mannum D130504	10
<i>Eucalyptus socialis</i>	Galga D270503	10
<i>Pittosporum angustifolium</i>	Moorlands MD 3041	7
Pyramid Hill		
<i>Acacia acinacea</i>	'Pyramid Hill'	6
<i>Acacia pycnantha</i>	'Pyramid Hill'	6
<i>Atriplex semibaccata</i>	'Pyramid Hill'	5
<i>Allocasuarina verticillata</i>	'Pyramid Hill'	5
<i>Callitris glaucophylla</i>	'Pyramid Hill'	5
<i>Dodonaea viscosa</i> subsp. <i>angustissima</i>	'Pyramid Hill'	5
<i>Eucalyptus microcarpa</i>	'Pyramid Hill'	4
<i>Eucalyptus melliodora</i>	'Pyramid Hill'	4

* formerly *Acacia calamifolia*. ** formerly *Callitris glaucophylla*

Sowing and site preparation

The seed was sown at both sites using *Burford* direct seeders (Figures 2 and 3) drawn behind four-wheel drive vehicles. The machine used at Pyramid Hill (Figure 3) was modified with a hopper for the application of 'Wattle Grow' and a tank and spray rig to apply smoke-impregnated water. At Palmer, a funnel and tube was used to manually apply the inoculant. Both seeders used two seed boxes to handle large and small seeds. The Burford seeder cuts a shallow groove with a disc. Small seeds are placed on the surface and pressed in with a rubber wheel. Large seeds (e.g. acacias) are placed deeper in the soil (1 cm) with a small boot and covered by two small harrows.



Figure 2: Neville Bonney sets up the Burford seeder for seeding at the Palmer site



Figure 3: David Millsom's modified Burford seeder

Table 2 shows the timing of the different sowings at each site and the conditions and weeds that were present. The autumn sowings were designed to take advantage of the onset of winter rains at these sites, but were delayed at both sites. We waited for these rains before sowing, as is the usual practice for temperate regions.

Table 2: Timing and site conditions for direct seeding treatments

Trial	Date of sowing	Temperature	Soil moisture*	Weeds present	Level of infestation
Palmer	17/9/2004	20°	MM	Salvation Jane, Potato Weed, Wire Weed	Moderate
	14/2/2005	27°	D	As above	Low
	25/6/2005	15°	D	As above	Low
Pyramid Hill	5/9/2005	15°	MM	As above	High
	23/9/2004	20°	MM	Salvation Jane, Cape Weed, Annual Ryegrass	High
	12/2/2005	28°	D	None	
	18/6/2005	12°	W	Salvation Jane, Cape Weed, Native grasses, Wild Oats	Moderate
	5/7/2005	14°	M	As above	Moderate

* Soil moisture in top 10 cm: W = Wet, M = Moist, MM = Minimal moisture, D = Dry.

The sites were not ripped prior to sowing. Weed control was carried out prior to each sowing treatment. Glyphosate herbicide was applied in strips where sowing was to occur using boom sprays at a rate of 3l/ha.

Measurements

Monitoring was carried out by Neville Bonney at the Palmer site and by David Millsom and Neville Bonney at the Pyramid Hill site. Germination was recorded approximately one 'season' after each sowing, i.e. the spring sowing was monitored in summer. In each 100m treatment plot, three randomly-selected 10m sample plots were marked. Table 3 shows the date that each sowing was monitored. In each sample the number of surviving germinants of each species was recorded. Ideally germination and survival would have been monitored on a monthly basis to ensure mortality events could be closely linked to environmental conditions, but the available resources did not allow this to occur.

The years during which this trial was carried out had climatic patterns different from long term trends, with a late arrival of the 'autumn break'. Summer temperatures in 2005 and 2006 were hotter than long term averages at both sites. Rainfall at Palmer was also considerably below average from October 2005 to August 2006. Annual rainfall totals for Palmer were 387mm (2004), 525mm (2005) and 262mm (2006 to 29/11), derived from Silo Data Drill estimates (see Appendix 1). Monthly rainfall and maximum and minimum temperature were recorded for each site during the trial period. Appendix 2 shows monthly rainfall and a sample of maximum and minimum temperatures recorded at the sites.

Analysis of variance was carried out on the data to compare between seasons and between species. Two-sample paired t-tests were used to compare seasons.

Table 3: Comparison between sowing and monitoring dates for Palmer and Pyramid Hill sites

Trial	Date of sowing	Date of monitoring	Duration (months)
Palmer	17/9/2004 ('spring')	15/2/2005	3
	14/2/2005 ('summer')	21/8/2006	18
	25/6/2005 ('autumn')	21/8/2006	14
	5/9/2005 ('winter')	21/8/2006	11
Pyramid Hill	23/9/2004 ('spring')	19/2/2005	5
	12/2/2005 ('summer')	10/6/2005	4
	18/6/2005 ('autumn')	2/10/2005	4
	5/7/2005 ('winter')	13/5/2006	10

Results

The effect of season of sowing

Figures 4 and 5 show the number of germinants recorded by species, for each of the four sowing events at Palmer and Pyramid Hill. These are the number of germinants that survived until the monitoring period. The number of germinants in Figures 4 and 5 represents the total number from twelve 10m sample plots, so could also be viewed as number of germinants per 120m of direct seeding. A dry, hot summer in 2005-06 saw many species that had germinated, fail to survive across all sowing treatments. Figures 9 and 11 in Appendix 1 show the rainfall during the trial period in relation to each of the sowing events.

For both trial sites there was poor survival (to 18 months for Palmer and 4 months for Pyramid Hill) for all species sown in summer. There were differences in germination among species for each sowing event, and each species had different germination and survival patterns in response to the four sowing seasons. There were also differences in survival from the same sowing within genera (e.g. *Eucalyptus* in Figs. 4 and 5). The poor results for Pyramid Hill for the winter planting can be attributed to a grasshopper plague after the seeds had germinated, which wiped out most plants.

The differences in length of time between sowing and monitoring for the four seasonal sowing treatments at the Palmer site, make comparisons between treatments difficult. However all sowing times at this site were monitored after being exposed to a summer. Observations from both sites indicate that summer is the time when high losses of young seedlings occur in any season, due to moisture stress, high temperatures and insect predation.

Effect of inoculant on survival of *Acacia* species

Figures 6 and 7 show the number of germinants surviving to monitoring for the two *Acacia* species used at each site, for each of the seasonal sowing treatments. There was a higher number of *Acacia* seedlings surviving at the Pyramid Hill site than at the Palmer site. At the Palmer site there is a trend for uninoculated treatments to have higher survival than inoculated treatments, although the differences are not significant. At Pyramid Hill inoculated treatments had significantly higher survival for *Acacia pycnantha* for the autumn and winter sowings and for *A. acinacea* for the autumn sowing.

Statistical analysis

Results of the ANOVA and two-sample paired t-tests are shown in Tables 4 and 6 (Pyramid Hill) and Tables 5 and 7 (Palmer).

In Tables 4 and 5, the F probability column indicates the probability that differences observed among species for that season are due to chance alone. In Tables 6 and 7, the F probability column indicates the probability that differences observed among seasons for that species are due to chance alone.

Results of t-tests between seasons indicate significant differences ($p < 0.05$) between results for spring/summer, spring/winter, summer/autumn and autumn/winter at Pyramid Hill (Table 4). At Palmer results of t-tests between seasons indicate significant differences ($p < 0.05$) between results for spring/summer and summer/winter (Table 5).

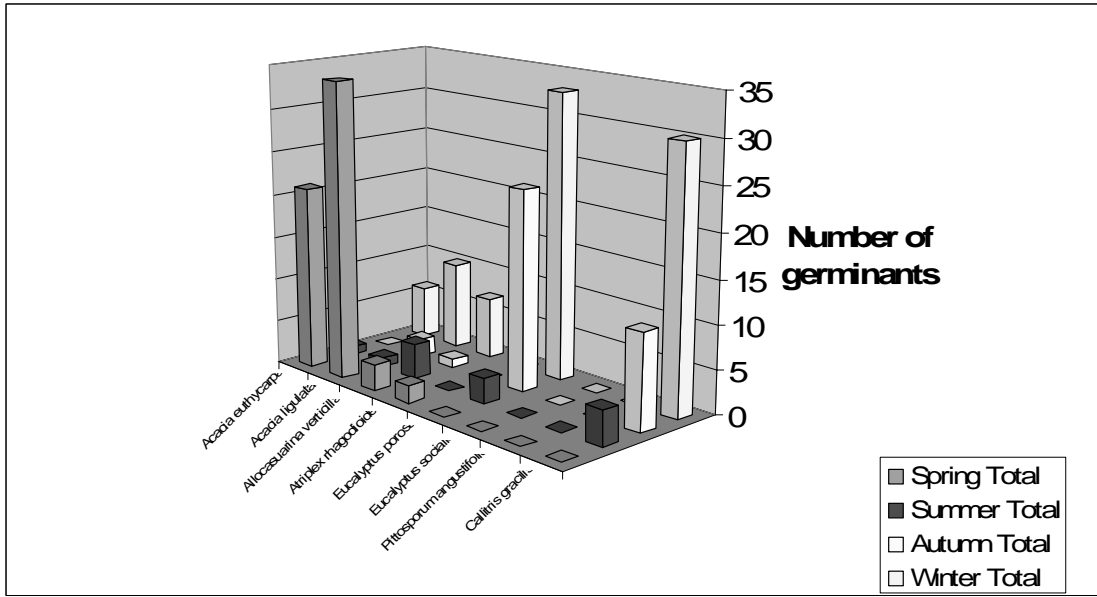


Figure 4: Palmer site - number of germinants surviving to monitoring for four seasonal sowings of eight species

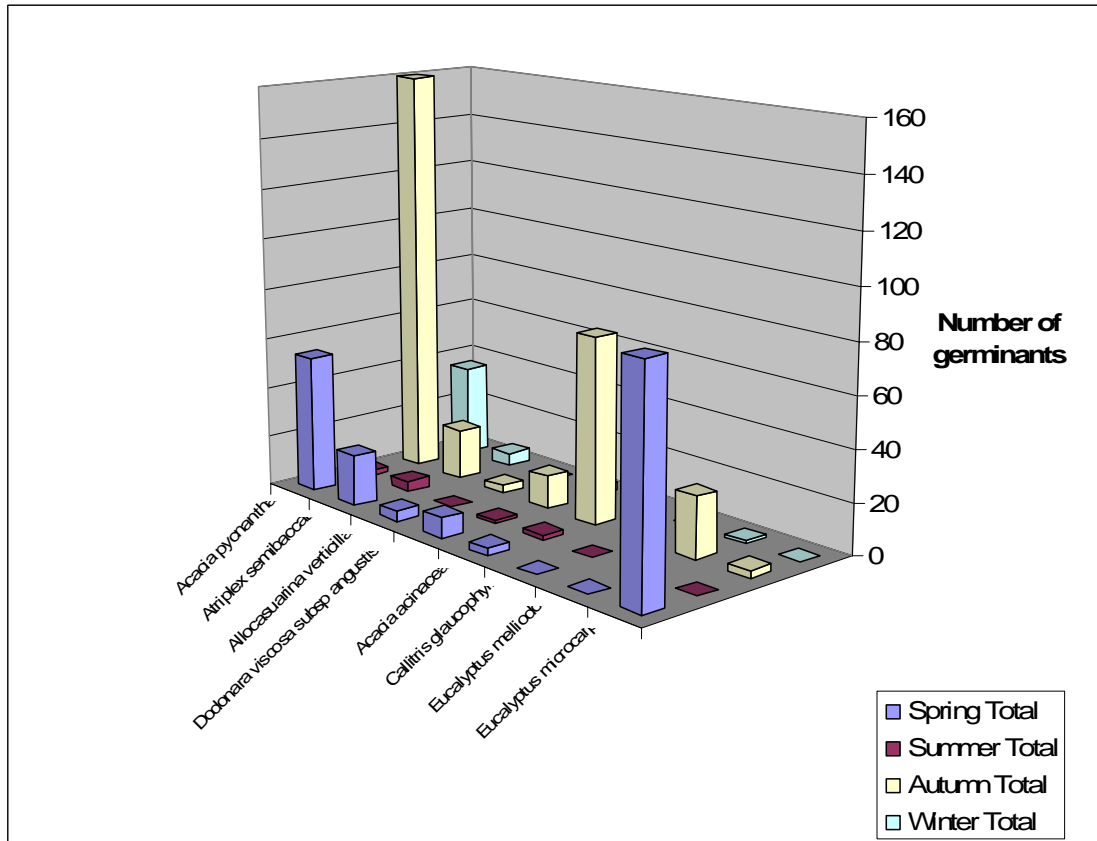


Figure 5: Pyramid Hill site - number of germinants surviving to monitoring for four seasonal sowings of eight species

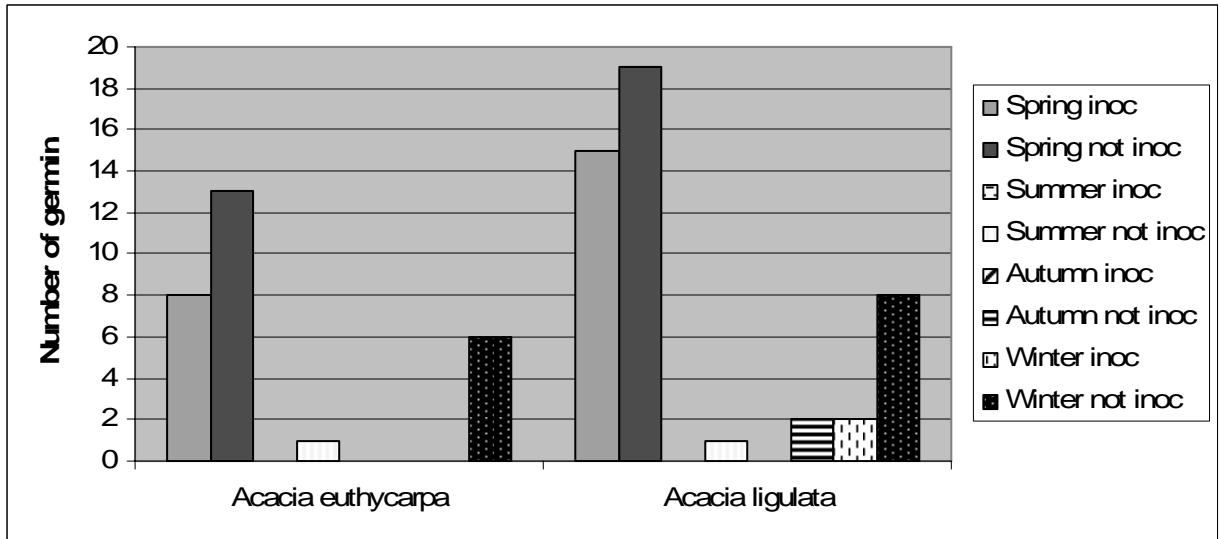


Figure 6: Number of germinants surviving to monitoring of two *Acacia* species in each season, with and without inoculant at Palmer.

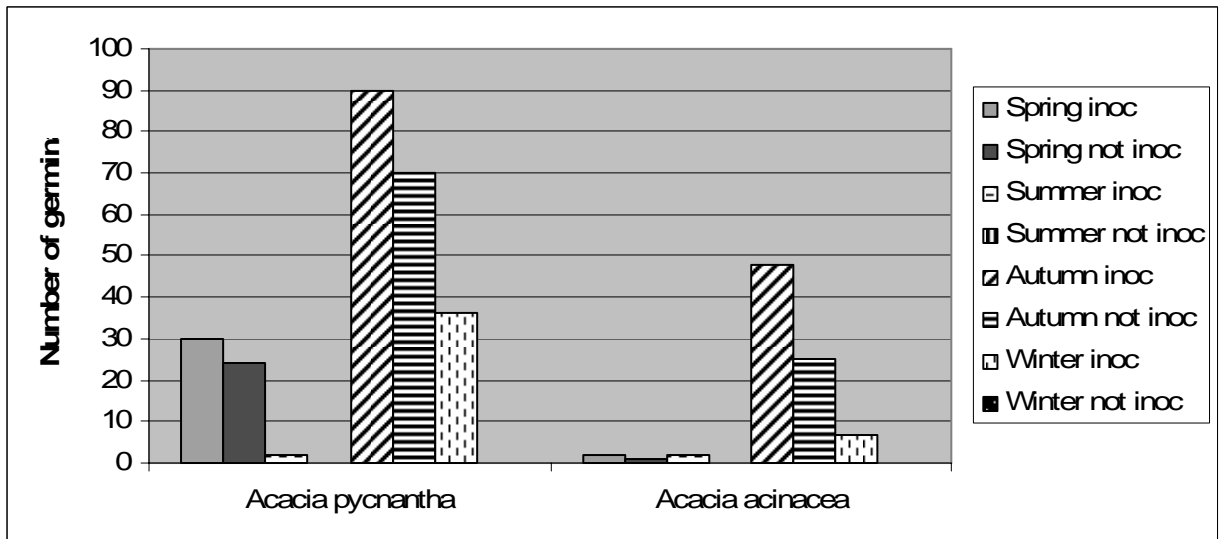


Figure 7: Number of germinants surviving to monitoring of two *Acacia* species in each season, with and without inoculant at Pyramid Hill.

The results and the statistical analysis show that for Palmer, there were significant differences in survival among species for the spring, autumn and winter sowings. This was also true at Pyramid Hill.

At Palmer, there were differences in survival across the four sowing times for *Acacia euthycarpa*, *A. ligulata* and *Callitris gracilis*. At Pyramid Hill there were differences in survival across the four sowing times for *Acacia pycnantha*, *A. acinacea*, *Eucalyptus melliodora* and *E. microcarpa*.

Table 4: Results of analysis of variance for differences among species for each season at Pyramid Hill

Season	F probability	Variance ratio	Degrees of freedom
Spring	<0.001	16.67	7,63
Summer	0.19	1.49	7,63
Autumn	<0.001	39.38	7,63
Winter	0.3	1.24	7,63

Table 5: Results of analysis of variance for differences among species for each season at Palmer

Season	F probability	Variance ratio	Degrees of freedom
Spring	<0.001	17.82	7, 63
Summer	0.5	0.92	7, 63
Autumn	<0.001	4.43	7, 63
Winter	0.022	2.61	7, 63

Table 6: Results of analysis of variance for differences among seasons for each species at Pyramid Hill

Species	F probability	Variance ratio	Degrees of freedom
<i>Acacia acinacea</i>	<0.001	24.28	3, 31
<i>Acacia pycnantha</i>	<0.001	13.4	3, 31
<i>Allocasuarina verticillata</i>	0.06	2.78	3, 31
<i>Atriplex semibaccata</i>	0.14	1.97	3, 31
<i>Callitris glaucophylla</i>	0.41	1	3, 31
<i>Dodonaea viscosa subsp. angustissima</i>	0.06	2.8	3, 31
<i>Eucalyptus microcarpa</i>	<0.001	7.8	3, 31
<i>Eucalyptus melliodora</i>	<0.001	28.04	3, 31

Table 7: Results of analysis of variance for differences among seasons for each species at Palmer

Species	F probability	Variance ratio	Degrees of freedom
<i>Acacia euthycarpa</i>	<0.001	12.72	3, 31
<i>Acacia ligulata</i>	<0.001	12.77	3, 31
<i>Allocasuarina verticillata</i>	-	-	
<i>Atriplex rhagodioides</i>	0.01	4.81	3, 31
<i>Callitris gracilis</i>	-	-	
<i>Eucalyptus porosa</i>	0.4	1.01	3, 31
<i>Eucalyptus socialis</i>	0.06	2.78	3, 31
<i>Pittosporum angustifolium</i>	0.16	1.88	3, 31

Discussion

All plants have optimal ranges of soil moisture and temperature for germination. In a nursery, these conditions can be controlled to an extent by artificial watering and heating. When seed is sown directly into the paddock, we have much less control over these environmental conditions. The only control we have is to sow the seeds when there is the highest probability of optimal conditions occurring in the field. Direct seeding practitioners have relied on their experience to predict when these conditions will occur in their area of operations, and carried out as much of their direct seeding within this window of opportunity as possible.

In most temperate regions, this window occurs in late winter or early spring when there is sufficient soil moisture (Carr *et al.*, in press). There is however, a compromise between sowing early to maximise moisture availability and sowing late enough to get temperatures high enough to stimulate germination. Availability of light also has an effect on germination (James, 1963). Germination may also be delayed by dormancy mechanisms in the seed or seed coat. For many species germination is triggered by a combination of several cues from the natural environment, often received in a particular order (Bell, 1999).

The results of this trial reinforce the need for greater understanding of the germination requirements of Australian species, to improve germination and survival following direct seeding. Seed that is sown when conditions are not right for germination must wait until those conditions are present. During this time the seed is prone to desiccation, predation and disease. If we are to use less seed in direct seeding, we need to ensure that seed is sown when it has the highest chance of germinating, in order to avoid these losses. The results from both Palmer and Pyramid Hill show that some species will have higher germination and survival in one particular season, and that the optimal season is not the same for all species. From the Victorian trial, *Acacia pycnantha* is clearly favoured by an autumn sowing, while *Eucalyptus microcarpa* is favoured by a spring sowing.

The results from this trial are a combination of germination success and survival, so a single cause cannot be accurately attributed to each result. To survive, a species must germinate and then survive the following seasonal conditions. A newly germinated seedling is very vulnerable to changes in moisture availability and temperature when compared to a one year old seedling.

The germination requirements of each species may, however, explain some of the variation among species at different sowings. Table 8 shows the optimal temperature ranges and response to heat shock for some of the species used in this trial.

Mean daily maximum temperatures are above 20°C at Pyramid Hill (Kerang weather station) and Palmer (Pallamana PO station) from October to April. Species shown in Table 8 that require temperatures higher than 20° would have only germinated within this period, provided other conditions were suitable. Seeds of these species sown in autumn and winter, would have not germinated close to sowing time and would therefore have been prone to predation. This may explain the poor germination and survival of *Eucalyptus microcarpa* in the autumn and winter sowings compared to the spring planting at Pyramid Hill, and possibly the similar results for *Acacia ligulata* and *A. euthycarpa* at Palmer. The wider germination temperature range for *A. ligulata* may explain why there was some germination and survival from the winter sowing.

Results for *Callitris gracilis* at Palmer show that this species germinated and survived better from the cooler sowings than the warmer sowings. With sufficient moisture, Adams (1999) found that *C. preissii* and *C. verrucosa* from the Eyre Peninsula had optimal germination at

18°C, indicating a tolerance to the increasing daytime temperatures in late winter. Early germination success of *Callitris* seedlings does not ensure successful survival during prolonged dry periods and there is often high mortality from successful germination events (Read, 1995). This may explain the survival profile of this species at Palmer, where survival of newly germinated seedlings sown in spring and summer is poor.

Eucalyptus porosa and *Acacia pycnantha* had better survival from the cooler month sowings, despite both having preferred germination temperatures around 25° C. The ability of seeds to take up water from the soil is the most critical factor in germination and varies from species to species. In the case of these two species, soil moisture may have been the limiting factor, indicating a preference for germination in the wetter autumn and winter sowings.

Table 8: Temperature and heat shock responses for species used in this trial (Bell, 1999)¹, (Langkamp, 1987)², (Gunn, 2001)³.

Species	Optimal temperature (range) for germination	Response to heat shock ¹
<i>Acacia acinacea</i> ³	25°	-
<i>Acacia ligulata</i> ³	20-25 °	-
<i>A. ligulata</i> ¹	12-30°	Promoted
<i>Acacia pycnantha</i> ¹	26°	Promoted
<i>Allocasuarina verticillata</i> ²	25-30 °	-
<i>Atriplex rhagodioides</i> ²	8-20°	-
<i>Dodonaea viscosa</i> ¹	20-25 °	Inhibited
<i>Eucalyptus melliodora</i> ³	25°	-
<i>E. microcarpa</i> ³	25°	-
<i>E. porosa</i> ³	25°	-
<i>E. socialis</i> ³	15°	-
<i>Eucalyptus socialis</i> ¹	12-28 °	-

The poor results from the summer plantings reinforce what is obvious to all direct seeders: that sowing when conditions are hot and dry is not conducive to germination and survival. It is highly likely that the seeds sown in summer did not germinate until moisture was available (early winter in this trial), by which time there may have been high losses of seed due to ant predation or desiccation. Alternatively, the seed may have germinated (there was rain in February at both sites), then been unable to survive the hot temperatures and declining soil moisture in late February and March.

At both sites the best overall germination and survival was in spring and autumn, and also in winter at Palmer. The results indicate that the current practice of planting in a window in spring is sound, but for some species, sowings conducted immediately after the ‘autumn break’ will also be successful.

The results show that even for what would be considered a ‘successful’ direct seeding event, such as that from Pyramid Hill for autumn, there is still considerable variation among species. In this event, *Callitris glaucophylla* did not survive and *Eucalyptus microcarpa* and *Allocasuarina verticillata* had poor survival. The spring sowing at this site however, had good germination of *E. microcarpa*. At Palmer the survival of *Acacia ligulata* and *A. euthycarpa* was good in spring but poor in other seasons. At this site survival of *E. porosa* and *C. gracilis* was good in autumn and winter but poor in the other seasons.

It appears that the use of the inoculant 'Wattle Grow' had a beneficial effect on the survival of the two *Acacia* species at Pyramid Hill compared to the uninoculated plants. This supports other studies that show that the inoculant helps survival by increasing the effectiveness of the root system in gaining access to soil moisture (Thrall *et al.*, 2001). It also increases plant growth, by increasing the available nitrogen, thus enabling deeper soil penetration by the root system to access greater reserves of moisture. *Wattle Grow* was developed through testing on a limited number of *Acacia* species, however, none of these were used in this trial (Thrall *et al.*, 2000).

Conclusions and recommendations

These results indicate to direct seeding practitioners that even with good site preparation and planning, sowing the whole suite of species together in a particular season at a particular site may not allow all species to germinate and survive. It is possible that some modification to the seed (coatings, insecticides, pre-germination) or to the environment (mulches, watering) may be able to improve the germination and survival of different species outside their optimum window (Carr *et al.*, in press), but sowing of targeted species in different seasons should be considered.

Until we can more precisely predict the range of environmental conditions that favour germination and early survival for all of our common species, practitioners must rely on observations they make in the field. This presents a strong case for practitioners to undertake regular monitoring of sites for several years after sowing. For each site, the following information should be recorded:

- Location
- Date of sowing
- Species used, including provenance
- Rate of sowing for each species
- Germination success 1-2 months after sowing
- Survival at 6-12 and 12-24 months.

Simple methods such as counting the number of germinants over a sample length of seeding line for each species will give an indication of success. The larger the seeding site, the longer the sample length should be. This will give a better indication of success than the usual method of glancing over the fence while driving by, as it indicates which species are favoured by the conditions. These records can then be compared with site-specific weather records to give an indication of how the conditions affected the germination and survival of individual species used on the site. Practitioners will then be able to build up a picture over time of which species are favoured by certain conditions.

The ideal moisture, light and temperature regimes for individual species should also be verified experimentally. This could then be matched to long-term climate averages for particular regions to predict the optimum sowing windows for individual species. The effect of inoculants such as ‘Wattle Grow’ should also be further tested for a range of *Acacia* species sown in different seasons and sites.

Long term regional experiments could also be established by community groups, regional NRM organisations, direct seeding practitioners and landholders to determine optimal sowing times for the species most commonly used in direct seeding. These experiments could sow identical batches of seed into small experimental rows in autumn, winter and spring over several years. Simple monitoring as outlined above would give an indication of which species will have better germination and survival in particular seasons, thus allowing better use of seed in annual direct seeding programs. Additional information such as soil moisture status on the surface and at 300mm, soil texture and surface roughness would add to the understanding of optimum conditions for germination.

In reality, monitoring is difficult for many direct seeding practitioners, as their success is measured (and they are paid), by how many kilometres of seeding they put in the ground. Government and private funding programs should specify that a portion of funding be put aside to carry out monitoring, as it will lead to better results on the ground and at a cheaper cost in the long term. Funding bodies, principally the Australian Government, through the Natural Heritage Trust should make monitoring and reporting a condition of funding.

To effectively achieve a national picture of species response to sowing times and climatic conditions, a national monitoring and reporting program should be established. Such a program would provide a simple method for field officers to use and a web-based database for reporting the results. Sufficient funding would also need to be provided to enable field collection of data, data entry and analysis to be undertaken. A critical component of such a system will be its ability to provide meaningful recommendations back to direct seeding practitioners.

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Appendix 1: Climate records for Palmer and Pyramid Hill trials

Derived from Silo Data Drill extrapolations from Queensland Department of Natural resources and Mines (Jeffrey *et al.*, 2001).

Rainfall during trial period at Palmer, SA

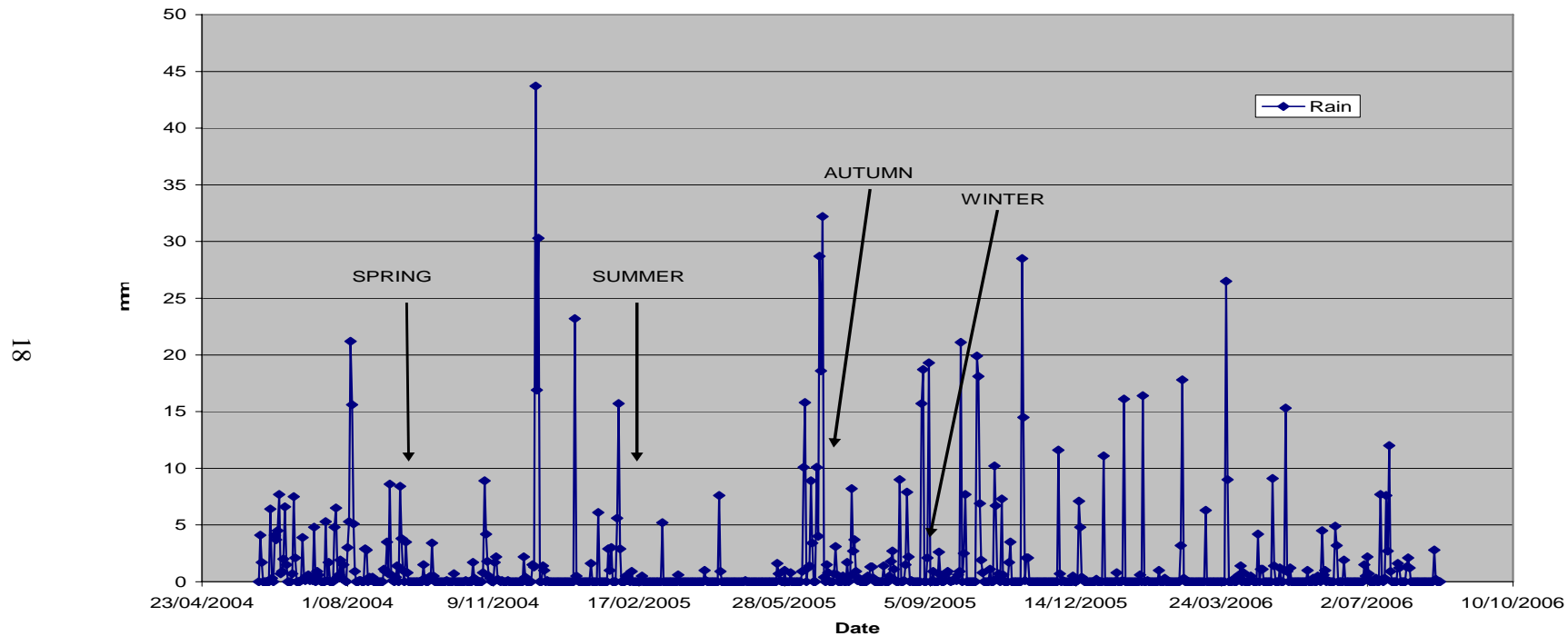


Figure 8: Daily rainfall data for Palmer site for the duration of the trial, showing dates of direct sowing events.

Evaporation and maximum temperature during trial period at Palmer, SA

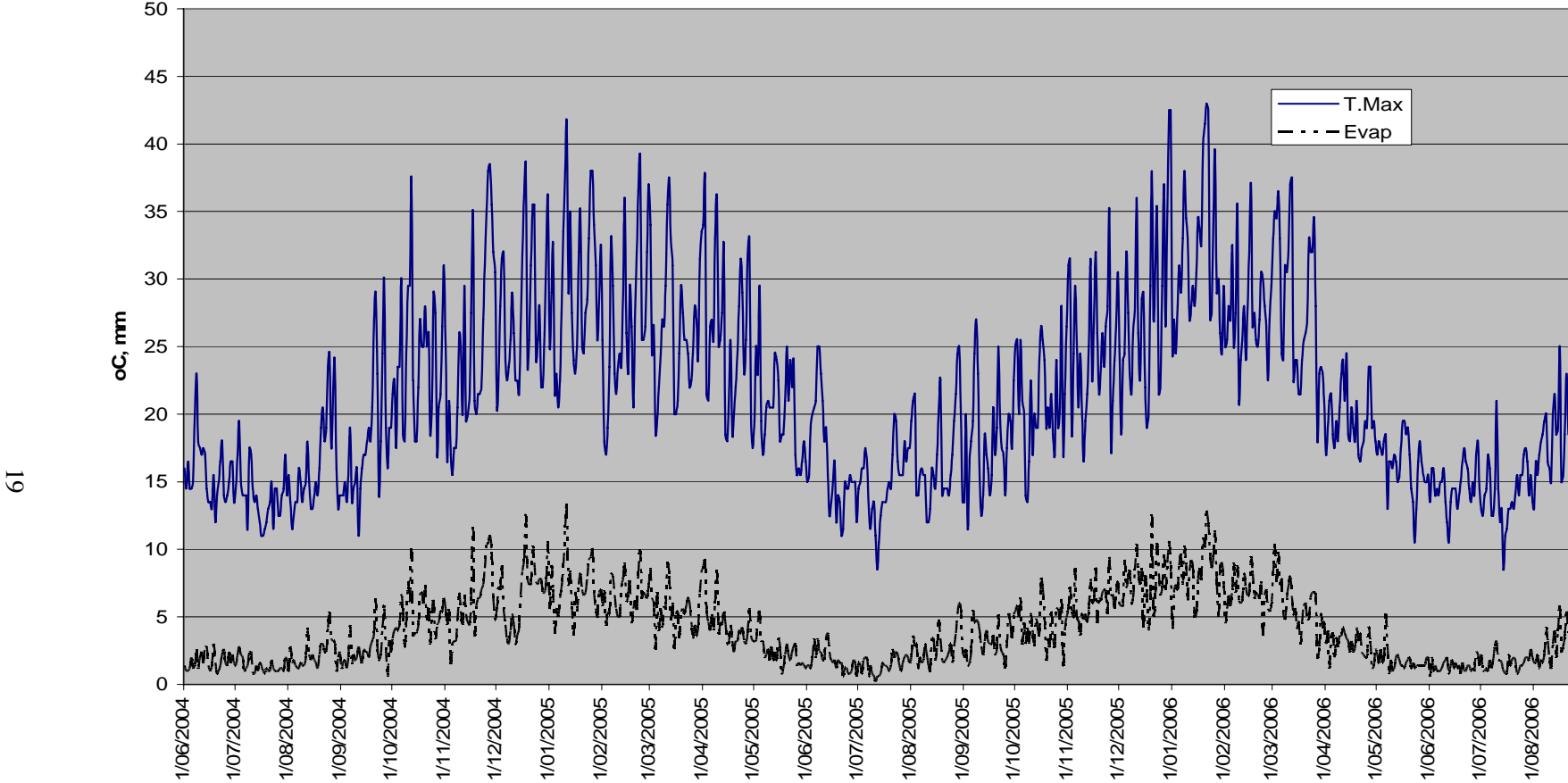


Figure 9: Daily maximum temperature (°C) and evaporation (mm) for Palmer site for the duration of the trial.

Rainfall during trial period at Pyramid Hill, Vic

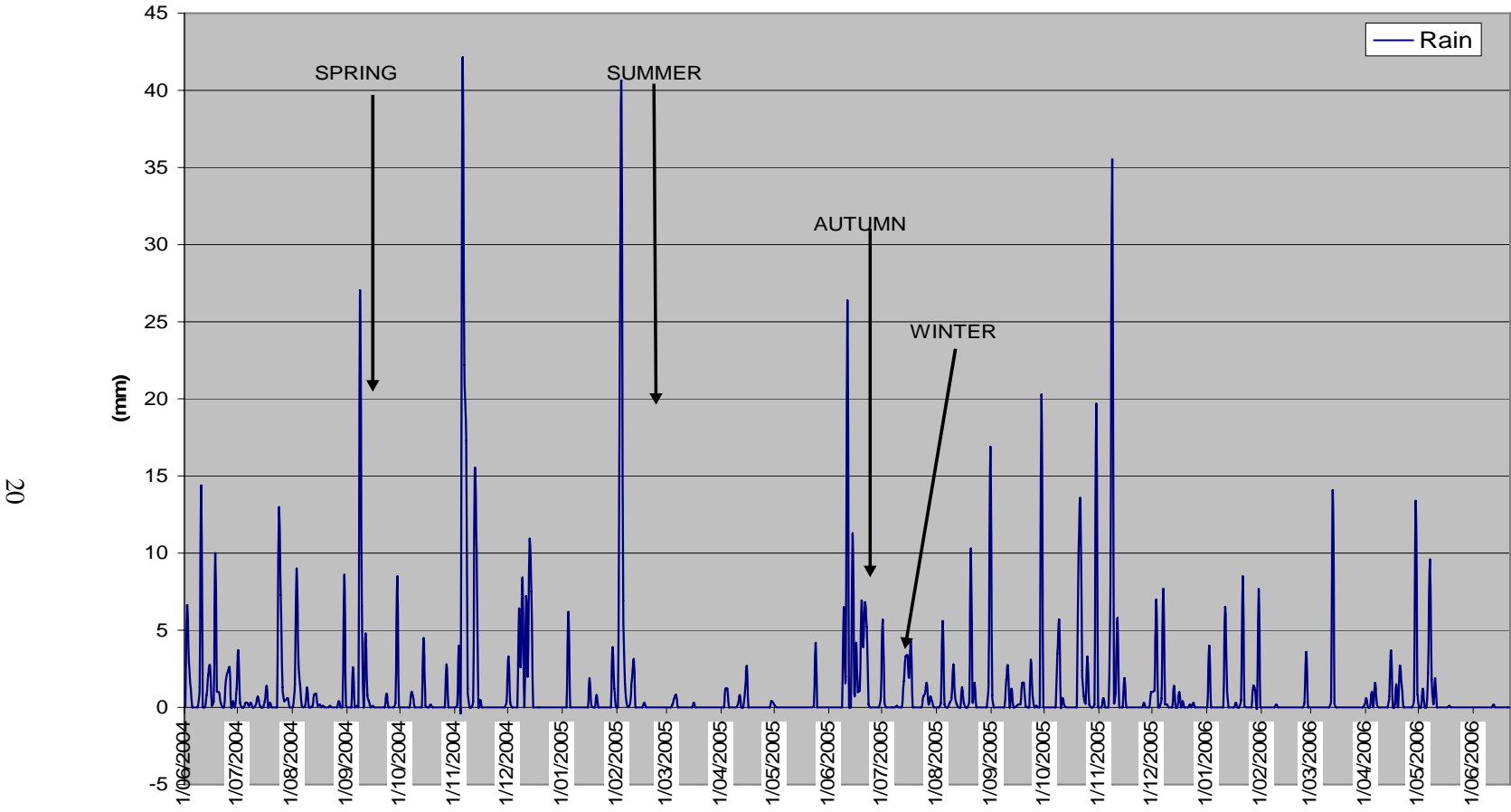


Figure 10: Daily rainfall data for Pyramid Hill site for the duration of the trial, showing dates of direct sowing events

Evaporation and maximum temperature during trial period at Pyramid Hill, Vic

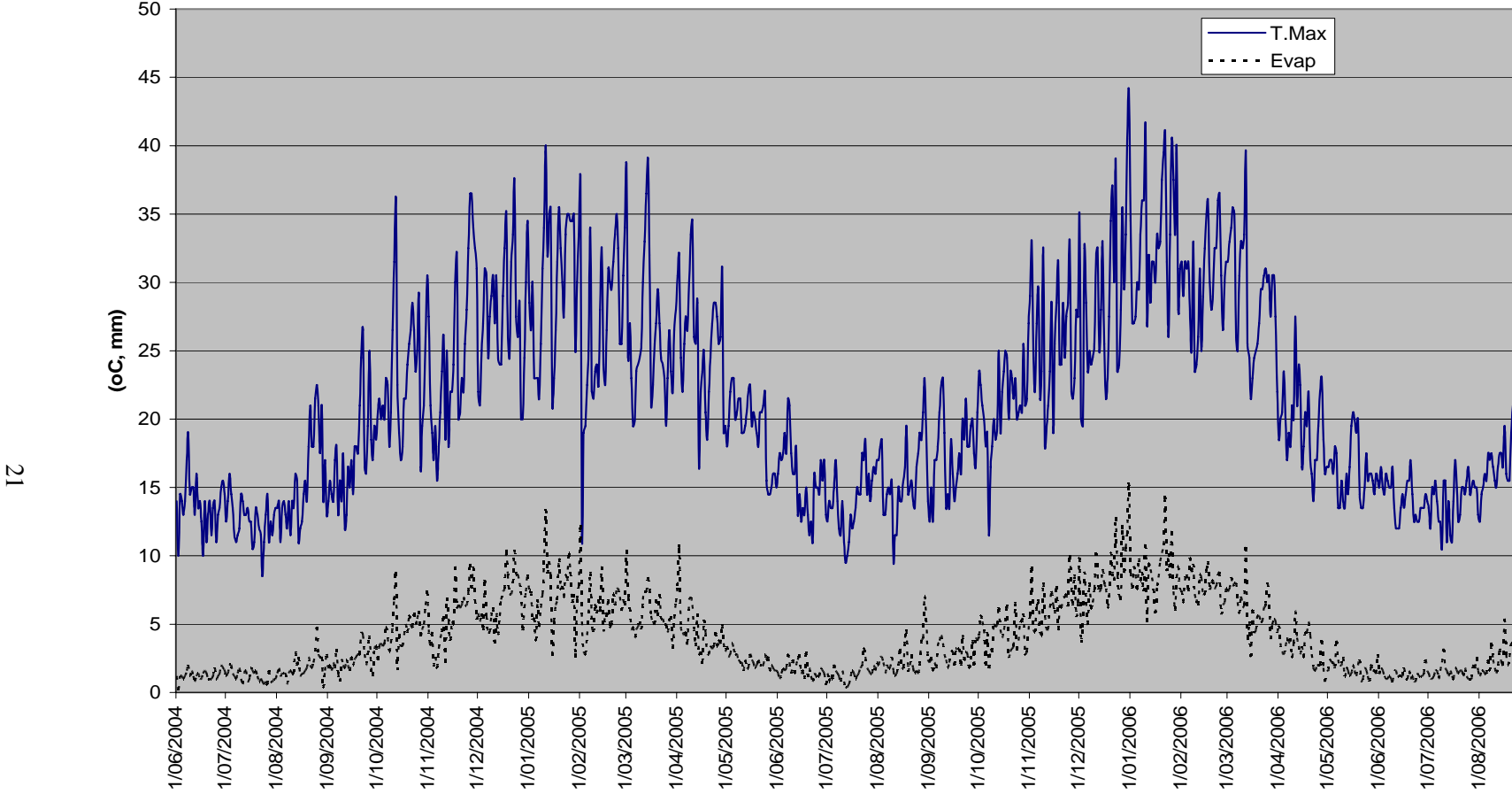


Figure 11: Daily maximum temperature (oC) and evaporation (mm) for Pyramid Hill site for the duration of the trial.

Appendix 2. Rainfall and temperature recorded at the trial sites

Monthly Rainfall at Pyramid Hill and Palmer from Jan 04 to Aug 06		
Date	Pyramid Hill	Palmer
2004	Rainfall (mm)	Rainfall (mm)
Jan	Not recorded	2
Feb	Not recorded	9
March	Not recorded	10
April	Not recorded	0
May	Not recorded	29
June	Not recorded	49
July	Not recorded	36
August	Not recorded	76
September	7	18
October	9	2
November	94	27
December	120	85
2004 Total	230	342
2005	Rainfall (mm)	Rainfall (mm)
Jan	21	30
Feb	67	26
March	0	5
April	6	7
May	1	3
June	51	134
July	15	20
August	27	54
September	34	55
October	53	77
November	49	41
December	27	21
2005 Total	351	471
2006	Rainfall (mm)	Rainfall (mm)
Jan	Not recorded	46
Feb	Not recorded	18
March	Not recorded	41
April	Not recorded	16
May	Not recorded	18
June	Not recorded	16
July	Not recorded	30
August	Not recorded	2
2006 Total	0	186

Temperature at Wallowa, near Palmer from Oct 04 to Jul 06		
Date	Min Temp	Max Temp
01-Oct-04	7	26
10-Oct-04	8	29
12-Oct-04	14	36
26-Nov-04	13	39
29-Nov-04	9	37
18-Dec-04	16	39
08-Jan-05	16	38
11-Jan-05	15	41
15-Jan-00	17	30
08-Feb-05	18	35
14-Feb-05	12	36
23-Feb-05	11	39
28-Feb-05	19	36
04-Mar-05	21	36
11-Mar-05	10	34
11-Mar-05	17	37
09-Apr-05	13	35
17-May-05	9	24
30-May-05	2	25
30-Jun-05	2	25
12-Jul-05	6	16
09-Aug-05	5	16
08-Sep-05	7	25
27-Sep-05	10	20
06-Oct-05	7	24
16-Oct-05	7	26
02-Nov-05	10	31
12-Nov-05	10	31
28-Nov-05	11	33
13-Dec-05	13	28
20-Dec-05	16	38
27-Dec-05	14	37
28-Dec-05	18	34
30-Dec-05	19	42
8/01/2006	16	38
15/01/2006	17	30
21/01/2006	35	44
8/02/2006	18	35
4/03/2006	21	36
11/03/2006	17	37
9/04/2006	8	19
23/04/2006	6	24
14/06/2006	-1	14
20/07/2006	1	21